

## Chapter 1

# Decision Making

This chapter presents basic concepts and methodologies of decision making, which will be used in describing fuzzy multi-objective group decision-making models, methods, systems, and applications presented in this book. We will briefly explain what the word *decision* means, what the particular characteristics of decision making are, how to model a decision problem, and what is involved in applying computerised support systems for a decision problem.

### 1.1 Decision and Decision Makers

Each organisation has its goals and achieves these goals through the use of resources such as people, material, money, and the performance of managerial functions such as planning, organising, directing, and controlling. To carry out these functions, managers are engaged in a continuous process of making decisions. Each decision is a reasoned choice among alternatives. The manager is thus a decision maker. However, decision makers can be managers at various levels, from a software development project manager to a CEO of a large company, and their decision problems can be various. Simple examples include deciding what to buy, when to visit a place, how to arrive there, who to employ, which grant to apply for, and deciding whom or what to vote for in an election. These problems can be in various logistics management, customer relationship management, marketing, and production planning.

Decisions can be made by individuals or groups. Individual decisions are often made at lower managerial levels and in small organisations, and group decisions are usually made at high managerial levels and large

organisations. There may be conflicting preferences for a group of decision makers, and may be conflicting objectives even for a sole decision maker. For example, in a product planning decision, an individual planner may consider profit, cost, and labour satisfaction as objectives. Obviously, the three objectives here are conflict with each other. When this problem is put in a group, except the conflict among the three objectives, some members may have more concern on profit and others may be on labour satisfaction. The decision making becomes more complicated as each individual preference needs to be considered in achieving an aggregated group decision.

The decision making is more complicated and difficult because the number of available alternatives is much larger today than ever before. Due to the availability of information technology and communication systems, especially the availability of the Internet and its search engines, we can find more information quickly and therefore generating more alternatives. Second, the cost of making errors can be very large because of the complexity of operations, automation, and the chain reaction that an error can cause in many parts, in both vertical and horizontal ways, of the organisation. Third, there are continuous changes in the fluctuating environment and more uncertainties in impacting elements, including information sources and information itself. More importantly, the rapid change of the decision environment requires decisions to be made quickly. These reasons cause organisational decision makers to require increasing technical support to help making high quality decisions. A high quality decision is expected to bring, such as in bank management, greater profitability, lower costs, shortening distribution times, increasing shareholder value, attracting more new customers, or having a certain percentage of customers respond positively to a direct mail campaign.

Many standard methods can be used to classify decision problems. One of the important classifications is based on a given problem structure: structured, semi-structured, or unstructured, the latter two are also called *ill-structured*. Different classes of decision problems may require different modelling and solution methods.

In a *structured problem*, the procedures for obtaining the best or the most satisfactory solution are known by standard solution methods. In general, such problems can be described by existing classic mathematical

models. For example, statistics is used to compare several products and to select one with the lowest cost.

An *unstructured problem* is fuzzy, for which there is no standard solution method. Human intuition is often the basis for decision making in an unstructured problem. Typical unstructured problems include planning new services, hiring an executive, or choosing a set of research and development projects for the next year.

*Semi-structured problems* fall between structured and unstructured problems, having both structured and unstructured elements. Solving them involves a combination of both standard solution procedures and human judgment.

## 1.2 Decision Making Process

Decision making is the cognitive process leading to the selection of a course of action among alternatives. Every decision-making process produces a final choice (sometimes called a *solution*). In general, a decision process begins when we need to find a solution but we do not know what and when a solution is accepted by decision makers. Decision making can be also seen as a reasoning process, which can be rational or irrational, and can be based on explicit assumptions or tacit assumptions.

A systematic decision-making process proposed by Simon (1977) involves three phases: *Intelligence*, *Design*, and *Choice*. A fourth phase, *Implementation*, was added later. Fig. 1.1 shows a conceptual picture of the four-phase decision-making process.

The decision making process starts with the *intelligence phase*, where the reality is examined, the problem is identified, and the problem statement is defined. In the *design phase*, a model that represents the system is constructed. This is done by making assumptions that simplify reality and by writing down the relationships among all variables. The model is then validated, and criteria are set for evaluation of the alternative courses of action that are identified. Often the process of model construction identifies potential alternative solutions, and vice versa. The *choice phase* includes selection of a proposed solution to the model. This solution is tested to determine its viability. Once the

proposed solution seems to be reasonable, we are ready for the last phase: *implementation*. Successful implementation results in solving the real problem. Failure leads to a return to an earlier phase of the process.

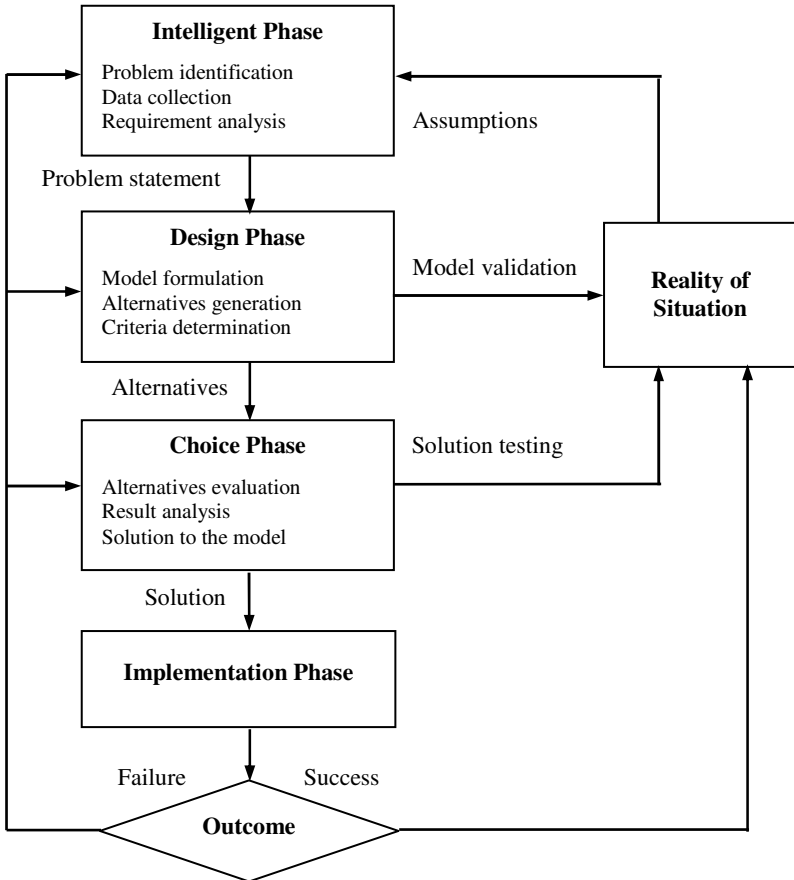


Fig. 1.1: Decision making process framework

Under the general decision process framework, different decision makers may emphasise one phase or another. Different decision-making problems may also require more details or sub-phases and support techniques in one or more phases. Literature on this subject shows many theories and results about how a decision is made, with some detailed and specific analysis and suggestions. To efficiently help decision

makers understand and easily follow a decision-making process, we list nine steps as an extension of the framework in Fig. 1.1.

### Step 1: Identify decision problems

To identify a decision problem includes good understanding on managerial assumptions, organisational boundaries, and any related initial and desired conditions. It aims to express the decision problem in a clear way and prepare a clear *problem statement*. This step, with Step 2 together, corresponds to the *intelligent phase* of the decision-making process framework. One example used here is to select an IT company for the development of an online consumer service (OCS) system for a business.

### Step 2: Analyse requirements

Requirements are conditions in which any acceptable solution to the problem must meet. In a mathematical form, these requirements are the constraints describing the set of the feasible solutions of the decision problem. Requirements can be obtained by collecting data and analysing the decision situation. The requirements for this example include the cost and the deadline of the OCS system development, and the connection with the current business information system.

### Step 3: Establish objectives and goals

The *design phase* of decision-making process starts from here and continues through to Step 6. This step identifies the important objectives of the decision problem and their goals. The objectives may be conflict but this is a natural concomitant of practical decision situations. The goals are the statements of intent and desirable programmatic values. In the mathematical form, the goals are objectives contrary to the requirements that are constraints. Not all objectives are of equal importance. Some are essential; whereas others are not absolutely necessary. For this example, the objective is to attract more customers through developing the OCS system.

#### Step 4: Generate alternatives

Objectives obtained will be used to help generating alternatives. But any alternative must meet the requirements. If the number of the possible alternatives is finite, we can check one by one if it meets the requirements. The infeasible ones must be deleted from the further consideration, and we obtain the explicit list of the alternatives. If the number of the possible alternatives is infinite, the set of alternatives is considered as that of the solutions fulfilling the constraints in the mathematical form of the requirements. In our example, three IT companies' responses are interested in the OCS system development and all can meet the cost and the deadline requirements, they are all as alternatives.

#### Step 5: Determine criteria if needed

To choose the best alternative, we need to evaluate all alternatives against objectives (Step 7). We may need some criteria to compare alternatives and to discriminate among alternatives, based on the objectives and goals. It is necessary to define discriminating criteria as objective measures of the goals to measure how well each alternative achieves the goals. In our example, to achieve the objective, to attract more customers, the OCS system developed should be user friendly, security, and easy to maintain, *etc.* This list of features can be used as criteria.

#### Step 6: Select a decision-making method or tool

In general, there are always several methods or tools available for solving a decision problem. The selection of an appropriate method or tool depends on the concrete decision problem and the preference of decision makers. Some methods are more suitable than others for a particular decision problem by a particular decision maker. Expertise and experience will help this selection. However, a principle is the simpler the method, the better. But complex decision problems may require more complex methods. In our example, as the decision is made in a group and linguistic terms may be used to express individual preference, a fuzzy Analytic Hierarchy Process (AHP) method (see Chapter 9) may be more suitable.

### Step 7: Evaluate alternatives against criteria

The *choice phase* of decision making begins with this step. A tentative decision will be made in this step through the evaluation of the alternatives against the objectives by using the determined criteria supported by the selected method or tool. With respect to some commonly shared and understood scale of measurement and the subjective assessment of the evaluation, the selected decision-making tool can be applied to rank the alternatives or to choose a subset of the most promising alternatives. In our example, by applying the selected method, one IT company is chosen to take the development of the OCS system.

### Step 8: Validate solutions against problem statements

If the tentatively chosen alternative has no significant adverse consequences, the choice is made. However, the alternatives selected by the applied decision-making method or tool have always to be validated against the requirements and goals of the decision problem. It may happen that the decision-making tool was misapplied. In complex problems the selected alternatives may also call the attention of decision makers that further goals or requirements should be added to the decision model.

### Step 9: Implement the problem

This step is to use the obtained solution to the decision problem.

From the process, we can see that the decision is a choice among various alternatives. Each decision can be characterised by a problem statement, a set of alternatives, and decision criteria. Decision makers go through all these phases in the process of reaching a decision. There is no any unified description of decision-making process. But a systematic decision-making process can help ensure that all aspects of decision making receive proper consideration and lends to computerised support.

### 1.3 Problem Modelling and Optimisation

From the decision-making process we have found that the core of the decision process is *design phase*, which is to formulate a model for an identified decision problem. In general, different types of models will require different kinds of decision-making methods. We list here some popular decision-making models, which will be used for one phase or the whole decision-making process.

*Analytic Hierarchy Process* (AHP) is a decision modelling technique that allows consideration of both qualitative and quantitative aspects of decisions. It reduces complex decisions to a series of one-on-one comparisons, and then synthesises the results. To use it, a detailed description of a hierarchy diagram will be given in Section 2.5.

*Paired Comparison Analysis* is used for working out the importance of a number of options related to each other. This makes it easy to choose the most important problem to solve, determine more important criteria to use, or select the solution that will give the greatest advantage. It also helps decision makers set priorities where there are conflicting demands on the resources.

*Grid Analysis*, also known as *decision matrix analysis* or *multi-attribute utility theory*, is a technique for supporting decision making. Decision matrices are most effective in which we have many alternatives and factors (criteria) to take into account. The first step is to list decision makers' alternatives and factors (criteria). Then it will work out the relative importance (weight) of factors in the decision. The weights will be used to decision makers' preferences by the importance of the factor.

*Decision Tree* is a graph of decisions and their possible consequences, used to create a plan to reach a goal. A decision tree, as a special form of tree structure, is a predictive model to map observations about an item with conclusions about the item's target value. Each interior node corresponds to a variable; an arc to a child represents a possible value of that variable. A leaf represents the predicted value of the target variable given the values of the variables represented by the path from the root.

*Optimisation model* is a more sophisticated approach to solving decision problem. Optimisation, also called *mathematical programming*,

refers to the study of decision problems in which one seeks to minimise or maximise a function by systematically choosing the values of variables from within an allowed set. An optimisation model includes three sets of elements: *decision variables*, *objective function(s)*, and *constraint(s)*. Many real-world decision problems can be modelled by an optimisation framework. There are many types of optimisation models such as linear programming, non-linear programming, multi-objective programming, multi-attribute programming, and multi-level programming.

*Linear Programming* is an important type of optimisation in which the objective function and constraints are all linear. Linear programming problems include specialised algorithms for their solution and for other types of optimisation problems by solving linear programming problems as sub-problems. Linear programming is heavily used in various management activities, either to maximise the profit or minimise the cost.

To model a decision problem by optimisation, we, in general, need three basic components: *decision variables*, *uncontrollable variables* (and/or *parameters*), and *result variables*.

*Decision Variables* describe alternative courses of action. The levels of these variables are determined by decision makers. For example, for a product planning problem, the amount to products produced is a decision variable.

*Uncontrollable Variables* or *Parameters* are the factors that affect the result variables but *are not under the control* of decision makers. Either of these factors can be fixed, in which they are called *parameters*, or they can vary, *variables*. These factors are uncontrollable because they are determined by elements of the system environment. Some of these variables limit decision makers and therefore form what are called the *constraints* of the problem. Examples are each product's produce cost, each product's marketing requirement and so on in a product planning problem.

*Result Variables* are outputs, reflecting the level of effectiveness of the system. The results of decisions are determined by decision makers (value of the decision variables), the factors that cannot be controlled by

decision makers, and the relationships among the variables. They can be the total profit and risk, rate of return in a product planning problem.

Now we use a linear programming model to explain how to build a model for a practical decision problem. A company produces two kinds of products:  $A_1$  and  $A_2$ . Each  $A_1$  can yield a profit of 4000 dollars per unit, and each  $A_2$  6000 dollars per unit. The decision problem is how many  $A_1$  and  $A_2$  should be produced in the first season of 2007. The objective is to obtain the maximised profit from producing the two products. However, the company has limitations in its labour, material, and marketing requirements. It needs 100 hours to produce one unit of  $A_1$ , and 200 hours to one unit of  $A_2$ , but it has only 100,000 hours labour available. The material costs of one unit of  $A_1$  and  $A_2$  are \$2000 and \$3000 respectively, and the total material budget is \$4,000,000. Also, it needs to produce at least 100 units of  $A_1$  and 200 units of  $A_2$  as marketing requirements. Within this product statement, we can determine the following:

*Decision variables:*

- $x_1$  = units of  $A_1$  to be produced;
- $x_2$  = units of  $A_2$  to be produced.

*Result variable (objective function):*

Maximise total profit:  $z = 4,000 x_1 + 6,000 x_2$ .

*Uncontrollable variables (constraints):*

- Labour constraint:  $100 x_1 + 200 x_2 \leq 100,000$  (hours);
- Material constraint:  $2,000 x_1 + 3,000 x_2 \leq 4,000,000$  (dollars);
- Marketing requirement for  $A_1$ :  $x_1 \geq 100$  (units);
- Marketing requirement for  $A_2$ :  $x_2 \geq 200$  (units).

This is a linear programming problem. Its formal model can be described as

$$\text{Max } z = 4000x_1 + 6000x_2$$

$$\text{s.t. } \begin{cases} 100x_1 + 200x_2 \leq 100,000 \\ 2,000x_1 + 3,000x_2 \leq 4,000,000 \\ x_1 \geq 100 \\ x_2 \geq 200 \end{cases}$$

By using a linear programming function of FMODSS in the attached CD, we can have the following result:

$$\begin{aligned} x_1 &= 600 \text{ (units)} \\ x_2 &= 200 \text{ (units)} \\ z &= 3,600,000 \text{ (dollars)} \end{aligned}$$

We can learn from this example on how to model a real-world problem. The existing decision models can help us find a way to model it and the existing decision support tools can support to generate a solution quickly.

We can find that optimisation is an ideal model for decision making. The only limitation is that it works only if the problem is structured and, for the most part, deterministic. An optimisation model defines the required input data, the desired output, and the mathematical relationships in a precise manner. Obviously, if the reality differs significantly from the assumptions used in developing the model, such a classic optimisation model cannot be used. However, a non-classical optimisation model (such as a fuzzy optimisation model) can be used.

As already discussed, many decisions are semi-structured or unstructured problems. This does not preclude using optimisation because many times a problem can be decomposed into sub-problems, some of which are structured enough for applying optimisation models. Also, optimisation can be combined with simulation and intelligent techniques, such as fuzzy logic and machine learning, for the solution of complex problems.

## 1.4 Computerised Decision Support

Due to the large number of elements including variables, functions, and parameters involved in many decisions, computerised decision support

has become a basic requirement to assist decision makers in considering and conducting the implications of various courses of decision making. In the meantime, the impact of computer technology, particularly Internet in recent years, on organisational management is increasing. Interaction and cooperation between users and computers are rapidly growing to cover more and more aspects of organisational decision activities. Internet or Intranet-based computerised information systems have now become vital to all kinds of organisations, including businesses and governments.

Therefore computer applications in organisations are moving from transactions processing and monitoring activities to problem analysis and solution finding. Web-based services are changing from online information presentation and data access to intelligent and personalised information delivery and product customization and recommendation. Internet or intranet-based online analytical processing and real-time decision support are becoming the cornerstones of modern management within the development of e-commerce, e-business and e-government. There is a trend toward providing managers with information systems that can assist them directly in their most important task: making decisions.

Computerised decision support technologies (models, methods, and systems) can help decision making in several aspects. First, computerised system allows decision makers to perform large numbers of computations, such as complex optimisation models, very quickly. It therefore makes many complex models be used in real decision problem solving, including some emergency situations, which needs to be responded in a very short time. Second, many decision problems involve data, which is stored in different databases, data warehouses, and at websites possibly outside the organisation. Also data may have different types, such as sound and graphics, and with complex relationships. Computerised technology can search, store, and transmit needed data quickly and economically for helping decision making. Third, computerised technology can help reduce the risk of human errors and improve decision results' reliability. Fourth, computerised support technique can improve the quality of the decisions made. Using computerised support, decision makers can understand the nature of the problem better, can perform complex simulations, check many possible

alternatives, and assess diverse impacts. For example, for a complex multi-objective programming problem, more alternatives can be obtained and evaluated, more uncertain data can be dealt with, more times of complex situations can be analysed and knowledge can be applied through linking with expert systems. All these capabilities lead to better decisions. Finally, computerised support can reduce decision cost. A good example is with the support of web-based systems, group members can be at different locations to have decision meetings.

The important issue is that with computerised technology, many complex decision-making tasks can be handled effectively now. However, computer based decision support techniques can be better useful in a structured decision problem than semi-structured and unstructured decision problems. In an unstructured problem only part of the problem can be supported by advanced decision support tools such as intelligent decision support systems. For semi-structured decision problems, the computerised support technology can improve the quality of the information on which the decision is based by providing not only a single solution but a range of alternative solutions. These capabilities will be further described in Chapter 4.