Game Theoretic and Analytical Approaches to

International Cooperation and Investment Problems

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(ABSTRACT)

International cooperation and foreign investment issues are two important components of an international economy. The various aspects of research related to such international cooperation and foreign investment decisions are fraught with various complex factors. In this thesis, we consider two specific issues in the arena of international technological cooperation and foreign investments, by using established Operations Research techniques of game theory and multiple criteria decision making.

We first analyze regional technological cooperation mechanisms using classical game theory. A concept of regional technological cooperation is developed based on a cooperative game theoretic model, in which a plan of payoff distributions induces an agreement that is acceptable to each participant. Under certain conditions, the underlying game is shown to be convex, and hence to have a nonempty core with the Shapley value allocations belonging to the core. A compensation scheme is devised based on the Shapley value allocations, whereby participants who enjoy a greater payoff with respect to the technological cooperation compensate the participants who receive a relatively lesser payoff via cooperation. In this manner, regional technological cooperation can bring overall benefits to all the involved players in the game. Some insightful examples are provided to illustrate the methodological concept.

Next, we discuss a model for analyzing foreign direct investment opportunities and for evaluating related projects based on the International Investment Attracting Force Theory and the technology of fuzzy evaluation. This model is applied to assess the industrial investment projects that were proposed in the *“ ’95 China’s Tumen River Area International Investment and Business Forum”* funded by the *United Nations Industrial Development Organization*. Accordingly, the projects are classified into groups based on their potential to attract foreign investors. Furthermore, we simulate the actual forming process whereby projects are sequenced and selected for funding by foreign investors based on a sequential update of their effect on the local economy. The results provide a scientific basis for formulating related decisions and policy recommendations regarding the various proposed projects.

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Chapter 1

Introduction

A consideration of foremost importance in solving any Operations Research problem is the formulation of a sufficiently representative mathematical model whose structure is amenable to appropriate analyses. In this thesis, we explore several techniques for constructing such desirable model representations, and illustrate the broad applicability of these techniques in solving contemporary problems arising in regional technological cooperation and foreign direct investment contexts.

1.1 Scope of Research

1.1.1 Regional Technological Cooperation

Technology is a type of production factor, and international technology transfer belongs to the realm of international trade. The objects of international trade are composed of products and production factors. While the theories of international trade that are related to products have been widely researched, the aspect of international trade pertaining to production factors has received relatively lesser attention. One of the main reasons is that there is no satisfying answer to the question on what would induce the countries holding technology to participate in technology transfer. Namely, how do the countries holding technology maintain and enhance competitive advantage while being involved in the technology transfer process? Unless some tangible benefits can be identified, such as future trade prospects, or geopolitical stability or advantage, the propensity would be toward an inherent monopoly of technology and a dearth of technology transfer.

The concept of international economic cooperation, which began to appear in 1945, was predicated on the premise that countries would coordinate with each other with respect to the realignment and redeployment of production factors in order to develop joint economies on a mutually beneficial basis (Feldstein, 1988, Li, 1997b, 1995, Tinbergen, 1945). This concept is referred to as a regional technological cooperation if it involves a particular technology field in a certain region. The mechanisms whereby the participating companies, enterprises, organizations, and individuals transfer or license technology, which might represent knowledge, tools, equipment, and work techniques used by an organization in delivering its products or services, subject to legal and political restrictions, constitute the overall process of technology transfer. Accordingly, regional technological cooperation is a devise to promote the technology transfer among countries in a certain region.

Because regional economic cooperation is one of the basic characters of the modern global economy, and the 21st century is poised to be an era that is driven by technology, regional technological cooperation is an important component in the process of global economic development. Generally, regional technological cooperation, as a special form of international technology transfer, has the following basic functions.

(1) Creating conditions to produce more wealth;
(2) helping to envigor the economic development among the participants in a complementary fashion, and to upgrade potential markets to real markets;
(3) helping not only the participants receiving the new technology to enhance their economic strength, but also enabling the participants holding the technology to strengthen their economic power through delayed trade and geopolitical benefits, and through continued development;
(4) providing all participants opportunities via jobs and low cost labor to realize common economic development;
(5) reducing the distinction in the status of the economy and technology among the participants;
(6) helping to promote free trade and investments within the region as well as on a global basis; and
(7) helping to generally improve the competitive advantage of every participant.

Having said this, the reality of the progress in regional technological cooperation practice has been slow. Because the expectations of key players are different and abiding principles are unclear, it is not surprising that concrete successful cases are lacking. Moreover, political, social, and cultural barriers further impede the process. At the same time, theoretical research addressing regional technological cooperation is lacking as well (APEC, 1997).

One of the principal aspects of a regional technological cooperation endeavor is the set of undertakings and agreements adopted by national governments that bind the rights and duties of the participants. This feature accords with the assumption which binds the actions of the players in a cooperative game (Roth, 1988, Shapley, 1971), as determined via solution concepts such as the core of the game or Shapley value allocations (Roth, 1988, Sherali and Rajan, 1986). By letting the countries that take part in such a cooperative framework be the players in a defined game, we can use the genre of game theory to bring to light inherent mechanisms that would induce regional technological cooperation.

This thesis explores the use of cooperative game theory to develop a modeling framework for regional technological cooperation. In the model, we exclude considerations such as how countries actually coordinate payoffs and establish checks and balances to enforce binding agreements. Such issues go beyond the scope of the present thesis and are governed by the dynamic circumstances that prevail once a general cooperative agreement as prompted by the game theoretic analysis has been adopted. Furthermore, we assume that each country participating in this cooperative game has complete information of the characteristic payoff functions of the game. This at least facilitates the development of undertakings and agreements that might have a self-binding propensity.

1.1.2 Foreign Direct Investment

Several large international investment merchant meetings are held every year, particularly in developing countries. These meetings are usually supported by a certain national government (or an area in a country), and/or a certain international organization (for example, the *United Nations Industrial Development Organization* (**UNIDO**)). The purpose of the merchants is to attract foreign direct investments for certain industrial projects (Aparicio 1999), Amirahmadi and Wu (1994), Graham and Krugman (1991), Grub and Lin (1991), and Sun (1998). With such a prominent focus to promote investments, many issues arise that need to be resolved. The host country's ultimate intent is to engage in joint ventures with all of these projects. However, this intent is passive and might not always be possible because several of the projects proposed by the host country might be of interest to foreign investors only if they are entirely acquired by them. Furthermore, the projects open for investment will likely have a great effect on the area's infrastructure, energy, capital, labor force, and municipal construction activities, and would need to be planned and sequenced in a timely fashion. Therefore, a more feasible situation for the host country is to manage the flow of investments as they occur over a certain period, sequencing them appropriately, while initiating a few each year. (A simultaneous investment activation of too many projects is often not a practical alternative.) The related questions that arise are what kinds of projects will attract foreign investments? How can one quantify the attracting force for such investments and predict which projects might finally be funded? In what order should the selected projects be sequenced? We address these questions in this thesis. The problem is complicated by the fact that not only does the economic evaluation of each individual project need to be considered, but also, the comprehensive joint evaluation of all the projects. The overall approach must heed the local developmental issues, while at the same time, be mindful of the investment motives and interests of the foreign investors. Moreover, because there exist interactions among the various projects, the problem is one of multi-feedback and interrelates the different investment decisions.

To illustrate the model and methodology discussed in this thesis, we present a detailed application to China's Tumen River Area. This area has a great potential for regional industrialization and is strategically located for becoming a central global goods flow area. As a result, the development of this region has enjoyed international interest since the 1990s. The *Tumen River Area Development Program* (**TRADP**), led by the *United Nations Development Program* (**UNDP**), has six participating countries in Northeast Asia: The People's Republic of China (PRC), The Republic of Korea (ROK), Russia, The Democratic People's Republic of Korea (DPRK), Mongolia, and Japan. One key issue in this joint venture, which is the focus of the present paper, is to promote investments for supporting TRADP, while another relates to free trade policies (see Li 1997, Li et al. 1995, 1996, UNDP 1995, UNIDO 1995a, 1995b, Xu and Li 1994, and the Yanbian Statistics Yearbook 1995). The development and opening-up of the Tumen River Area has been included in the "ninth five years" plan and in the 2010 long-range objective outline for China's national economy and social development. The *" '95 China's Tumen River Area International Investment and Business Forum"*, funded by UNIDO, was successfully held in 1995. Some 116 industrial projects screened by UNIDO were proposed. The objective of UNIDO in promoting investments in this area was to provide an impetus in developing an influential pole in the Tumen River Growth Triangle.

In this thesis, based on the International Investment Attracting Force Theory (Wang 1993) and the Fuzzy Evaluation Technology (Dai 1994), we present a new methodology for evaluating foreign direct investment projects, and illustrate its application to the China's Tumen River Area developmental venture. In particular, we provide a comprehensive evaluation of the projects that were proposed in the *" '95 China's Tumen River Area International Investment and Business Forum"*, and subsequently, we simulate their flow process. In this illustrative study, since there is a lack of original data for 13 of the total of 116 projects, only 103 of these 116 projects have been classified and evaluated. The results of this study provide a scientific basis for (1) further evaluating and analyzing these projects, (2) studying the effects of these projects on the infrastructure, social economy, and especially, on the manufacturing sector of China's Tumen River Area, and (3) formulating short and long-term decisions and policies for continued development in the area.

1.2 Organization of the Thesis

The remainder of this thesis is organized as follows.

In Chapter 2, we review the literature on techniques of Operations Research (OR), Multiple Criteria Decision Making (MCDM), the Analytic Hierarchy Process (AHP), cooperative game and Shapley value, and Foreign Direct Investment (FDI).

In Chapter3, we begin in Section 3.1 by discussing certain basic concepts pertaining to regional technological cooperation as well as general cooperative game theory. Based on these concepts, we propose in Section 3.2 the framework of a cooperative game to represent a regional technology transfer mechanism among participating countries, and establish that this game is convex, and hence that the Shapley value allocations belong to its core. A closed-form expression is derived for the allocation scheme, which affords interesting economic interpretations. Section 3.3 provides some insightful illustrative examples.

In Chapter 4, we begin in Section 4.1 by constructing a general model to evaluate the projects in the " *'95 China's Tumen River Area International Investment and Business Forum*", including the target system, the evaluation submodel, the expert system, and the simulation submodel. Based on these concepts and techniques, we analyze in Section 4.2 the results of the evaluation process and obtain a rank ordering for all the considered 103 projects.

Finally, Chapter 5 presents a summary and concluding remarks. Section 5.1 concludes the regional technological cooperation part of the thesis with comments related to the overall technology transfer process. Some remarks related to the decisions and to policies for handling existing and potential issues are provided in Section 5.2.

Chapter 2

Literature Review

This chapter reviews literature related to the topics discussed in this thesis. We begin in Section 2.1 by reviewing some fundamental concepts of the Operations Research techniques implemented in this research. Section 2.2 provides an overview of Multiple Criteria Decision Making (MCDM). In Section 2.3, we introduce key concepts of the Analytic Hierarchy Process (AHP) technique. Finally, we review some fundamental ideas related to cooperative games, Shapley value, and Foreign Direct Investment (FDI).

2.1 Techniques of Operations Research (OR)

Operation Research is the scientific approach to decision making that involves the operations of organizational systems (Hillier and Liberman, 1980). As its name implies, operations research involves research on operations. This says something about both the approach and the area of the application of the field. Operations Research has been applied extensively in business, industry, the military, civil government and agencies, hospitals, and so forth. The approach of operations research is that of the scientific method. In particular, the process begins by carefully observing and formulating the problem and then constructing a scientific, typically mathematical, model that attempts to abstract the essence of the real problem. It is then hypothesized that this model is a sufficiently precise representation of the essential features of the situation, so that the conclusions (solutions) derived from the model are also valid for the real problem. This hypothesis is then verified, validated, and revised as necessary by suitable experimentation. Thus, in a certain sense operations research involves creative scientific research into the fundamental properties of operations.

The roots of operation research can be traced back many decades, when early attempts were made to use a scientific approach in the management of organizations. Generally, there are the following techniques of OR (Taha, 1997, Hillier and Liberman, 1980) in deterministic and probabilistic forms: linear programming, nonlinear programming, dynamic programming, integer programming, stochastic programming, goal programming, transportation analyses, network flows, forecasting, inventory theory, queuing theory, game theory, decision analysis, Markovian decision processes, and simulation techniques, and so on.

2.2 Multiple Criteria Decision Making (MCDM)

Multiple criteria decision making (MCDM) or multiple attribute decision making (MADM) is an area of decision technology which has seen a considerable development during the last two decades into a discipline in its own right (Stewart, 1992). Researchers from a wide variety of disciplines have investigated multiple decision making problems since the eighteenth century (Iz, 1993). Other general references include Roy (1990), Bell et al. (1988), French (1986), Zeleny (1982), Stewart (1992), and Edwards (1967).

As its name indicates, MCDM aims to provide the decision maker with some tools in order to make advances in solving a decision problem where several, perhaps contradictory, points of view must be taken into account. MCDM is designed to help individuals and organizations make informed inferences and decisions. Ideas have been synthesized from economics, statistics, psychology, operation research, education, and other disciplines in order to give the decision-maker tools to enable and enhance his /her abilities in solving decision problems (See Bana, Costa, and Vincke (1990) for an overview of MCDM, and also Vincke (1992)). Various applications are discussed in Lootsma (1987) and Belton (1990).

MCDM can be classified as either discrete or continuous. The former refers to MCDM problems which are characterized by a small number of distinct alternatives evaluated on a number of attributes. The continuous type MCDM problem are characterized by a large number of implicit alternatives i.e. alternatives are hidden in the functional forms of the constraints. The objectives are also defined in clear functional form. These types of problems are widely known as multiple objective decision making (MODM) problems.

Decision makers often deal with problems that involve multiple conflicting criteria. These may range from those affecting common households, such as the purchase of a car, to those affecting entire nations, as in the judicious use of dollars for the preservation of national security. For example, in purchasing a family car, the following multiple attributes may be considered: price, comfort (roominess), fuel economy, safety, maintenance cost, depreciation, appeal, and so on. The job one chooses may depend upon its prestige, location, salary, advancement opportunities, working conditions, and so on (Yoon, 1995).

MCDM refers to making preference decisions (e.g., evaluation, prioritizing, selection) over the available alternatives that are characterized by multiple, usually conflicting attributes.

2.3 The Analytic Hierarchy Process (AHP)

The purpose of the Analytic Hierarchy Process (Saaty, 1980) is to develop a theory and provide a methodology for modeling unstructured problems in the economic, social, and management sciences. The framework of the Analytic Hierarchy Process is a very useful tool for the solution of diverse and numerous application oriented problems. Saaty defines a hierarchy as particular type of system. In particular, any system can be divided into two parts: structure and function. Actually, the structure and function of a system cannot be separated. In fact, the structure serves as a vehicle for analyzing the function. The functioning modifies the dynamics of the structure. A hierarchy is an abstraction of the structure of a system to study the functional interactions of its components and their impacts on the entire system.

Using the Analytic Hierarchy Process in solving a decision problem involves four main steps (Zahedi, 1986):

Step 1: Setting up the decision hierarchy by breaking down the decision problem into a hierarchy of interrelated decision elements.
Step 2: Collecting input data by a pairwise comparisons of decision elements, i.e., by comparing the options under each criterion. This method uses a semantic scale and associated 1-9 ratio scale.
Step 3: Using the "eigenvalue" method to estimate the relative weights of the decision elements at each level of the hierarchy.
Step 4: Aggregating the relative weights of the decision elements by using the weighted arithmetic mean to obtain the final scores for the decision options.

2.4 Cooperative Games and Shapley Value

Much of the modern theory of games traces its origins to the monumental book (Jon von Newmenn and Morgenstern, 1944), although game theoretic ideas can be traced further back in time. Generally, games are divided into two kinds – noncooperative games and cooperative games. Noncooperative games are played by players who choose their strategies independently, whereas in cooperative games, coalition formation and joint actions are allowed and are generally preferred to acting alone.

When using the characteristic function $v(\bullet)$ to research an n-player cooperative game (N,v), where N is the set of all the n players, if one assumes that all players weigh their payoffs by the same measure and that the payoff $v(S)$ of every coalition $S \subseteq N$ can be distributed to the participants in S using some appropriate method, then the payoffs (utilities) of the players are said to be transferable. If one assumes that the players form the grand coalition by entering one by one in some order and that all $n!$ orderings of the players N are equally likely, then a type of fair distribution plan for allocating the payoff $v(N)$ of the grand coalition N is given by

$$x_i \equiv \varphi_i(N,v) = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{(|S|-1)!(n-|S|)!}{n!}[v(S) - v(S-\{i\})], \qquad \forall i = 1,\cdots,n,$$

where x_i $(\forall i \in S)$ is the excepted marginal contribution made by player i by entering the coalition, and $|S|$ denotes the cardinality of the coalition $S \subseteq N$. The collection $\{\varphi_i(N,v)\}_{i \in N}$ is called a set of *Shapley Values* (Shapley 1953).

So far, the concept and technique of Shapley Values has been widely applied to various areas: reformulations and generalizations, coalitions, large games, cost allocation and fair division, nontransferable utility games, noncooperative game theory, and so on (see Forgo, Szep, and Szidarovszky, 1999, Roth, 1988, and Rubinstein, 1990).

2.5 Foreign Direct Investment (FDI)

The theory related to **attracting foreign investments** is at an elementary stage (Li and Zu, 1992). On the other hand, there are several supporting concepts that are relatively well-developed, such as the monopolistic advantage theory, the oligopoly action theory, the comparative advantage theory, the product life-cycle theory, the international production theory, firm growth theory, location theory, and capitalization theory (see Buckley 1990, and Lindert and Pugel 1996). However, while these theories provide useful insights, they are confined within application limits, and cannot explain many specific issues that arise in the context of international investments. In contrast, with appropriate modifications and used in concert with other techniques discussed below, the International Investment Attracting Force Theory contributes much to solving the problems in this thesis (Wang 1993). In general, this theory encompasses: (1) the international investment motive force theory to explain why foreign investors venture capital in some host country; (2) the international investment attracting force theory to explain why the international assets enter the particular host country and do not enter other countries; (3) the international investment inertia theory to explain why the investments in the host country maintain some level of capital flow; and (4) the international investment attracting force model to analyze the direct investments.

A second issue of interest in this thesis is that of **investment evaluation** which is concerned with the comprehensive economic evaluation of multiple projects. In general, this process is facilitated by several techniques such as cost-benefit analyses, the L-M method (a quantitative method of Little and Mirlees 1974), the S-V method (a quantitative method of Spuire and Van der Tak 1975), the Increasing Value Method of UNIDO, the Fuzzy Evaluation Method (which is a method that combines a qualitative evaluation process with a quantitative evaluation technique, using fuzzy decision-making concepts (see Dai 1994), and the group decision-making and group decision support systems technology (e.g. expert systems - see Marchant, 2000). We also refer the reader to Canada et al. (1996) and Irvin 1991 for further discussion on these approaches.

Chapter 3

Game Theoretic Analysis of Mechanisms to Induce Regional Technological Cooperation

In this Chapter, we develop the concept of regional technological cooperation and study a contemporary application of Shapley value in this area. Sections 3.1, 3.2, and 3.3 respectively describe the basic concepts of regional technological cooperation, a mechanism of regional technological cooperation, and provide insightful illustrative examples.

3.1 Basic Concepts

3.1.1 The Definition of Regional Technological Cooperation

By the discussion in Section 1.1 and that in Li (1995), we can define a regional technological cooperation framework as follows.

Definition 3.1: *Regional technological cooperation* is a coordinated effort between the governments of two or more countries in a certain geographical region in order to promote their mutual economic and political development and technological advancements.

The goal of regional technological cooperation is to strengthen the economic, technological, and political bases of all the participants to their mutual benefit. These goals and subsequent actions are governed by a set of policies that are formulated by each participant. Such a concept can be represented by denoting the Regional Technological Cooperation (RTC) phenomenon as

$$\text{RTC} = \{N, G, P\}$$

where, N, G, and P denote the three aforementioned components of this process, defined as follows. The set $N = \{1, \cdots, n\}$ denotes the n participating countries in the regional technological cooperation; G is the comprehensive goal of RTC constituted by the union of the goals G_i of participating country i in RTC; and likewise, P is the union of the respective policies and measures P_i adopted by participating country i in achieving its goals within the RTC.

For example, The Asia-Pacific Economic Cooperation (APEC) was established in 1989 in response to the growing interdependence among Asian-Pacific economies. Presently, it includes $n = 21$ members (Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; Republic of the Philippines; Russia; Singapore; Chinese Taipei; Thailand; United States; and Vietnam). Its goal (G) is to advance the Asian-Pacific economic dynamism and sense of community. Through dialogues, the members engage in economic and technical cooperation which include the following six areas and constitute the set P : developing human capital; fostering safe and efficient capital markets; strengthening the economic infrastructure; harnessing technologies of the future; promoting environmentally sustainable growth; and encouraging the growth of small and medium-sized enterprises.

Naturally, some common ground should exist among the individual goals and policies to foster a joint cooperative agreement. This common ground, in essence, defines the characteristic function of the cooperative game as discussed in the sequel.

3.1.2 Basic Concepts of Game Theory
Generally, a standard game is defined as:

$$\Gamma = \{ N , (C_i)_{i \in N} , (u_i)_{i \in N} \}$$

in which N is a non-empty set of players, C_i is the non-empty set of all possible strategies that are feasible for Player i, and u_i is the payoff function for Player i .

Definition 3.2 (Shapley, 1971): For a set $N = \{1, \cdots, n\}$ of players, each non-empty subset $S \subseteq N$ of cooperating players is called a *coalition*. The (power) set of all possible coalitions is denoted by $P(N)$.

For instance, using the illustrative example of the foregoing subsection, $S = \{$ Canada, Mexico, United States $\}$ based on the North American Free Trade Agreement, and $S = \{$ China, Japan, Republic of Korea $\}$ based on their Summit Meeting coordinated by the Association of South-East Asian Nations (ASEAN) are two such existing coalitions, while some other “coalitions” could be comprised of simply individual countries.

In a cooperative game, the incentive for players to take part in coalitions is governed by a so-called characteristic function which is defined as follows.

Definition 3.3 (Shapley, 1971): The *characteristic function* of an n -player cooperative game is a real function $v(S)$ defined on $P(N)$, which indicates the payoff that Coalition S can receive by means of coordinating the strategies of the participants within S . Obviously, $v(\emptyset) \equiv 0$, where $\emptyset$ is the empty set.

Definition 3.4 (Shapley, 1971): A characteristic function is called *supperadditive* if for any two disjoint coalitions S and T , we have that their payoff under a joint coalition is not less than the sum of their independent payoffs, that is

$$v(S \bigcup T) \geq v(S) + v(T), \ \forall S, T \subseteq N, S \bigcap T = \emptyset .$$

Definition 3.5 (Shapley, 1971): A game with characteristic function v is *convex* if

$$v(S)+v(T)\le v(S\bigcup T)+v(S\bigcap T)$$

for each $S,T\subseteq N$. Equivalently, a game is convex if

$$v(T\bigcup\{i\})-v(T)\ge v(S\bigcup\{i\})-v(S),\forall S\subseteq T\subset N, i\in N-T.$$

Note that by definition, a convex game is supperadditive.

Definition 3.6 (Myerson, 1991): A game Γ with *transferable utility* is one for which in addition to the strategy options listed in C_i, each player i has the option to give any number of units of payoff to any other player, including to itself (i.e. self-consumption), where each unit of payoff corresponds to a unit of utility.

When using the characteristic function to research an n-player cooperative game (N,v), we assume that all players weigh their payoffs by the same measure, and that the payoff $v(S)$ of every coalition can be distributed to participants using some appropriate method. Namely, the payoffs (utilities) of the players are transferable.

Similar to the concept of *trade creation* (Viner, 1950), we can define the concept of technology transfer creation as follows.

Definition 3.7: *Technology transfer creation* is the process by which the formation of a cooperative coalition for the purpose of technology transfer increases the net benefit or general welfare of every player in the coalition.

Definition 3.8 (Shapley, 1971): A *payment vector*

$$\boldsymbol{x}=(x_1,\cdots,x_n)\in R^n$$

defines for each player $i\in N$, a share x_i which this player gains from the payoff of the coalition.

Definition 3.9 (Shapley, 1971): A payment vector $\boldsymbol{x}$ is called a *distribution* for a cooperative game based on a grand coalition N and having a characteristic function v if

$$x_i\ge v(\{i\})\qquad \forall i=1,\cdots,n \tag{3.1}$$

and

$$\sum_{i\in N}x_i=v(N)\,. \tag{3.2}$$

The set of all possible distributions is denoted by $E(v)$.

Relation (3.1) is called the individual rational condition, since it indicates that the payoff gained by any player i is not less than the payoff available to i by taking independent action. Relation (3.2) is called the collective rational condition, since it indicates that the payment function, assuming a grand coalition, should distribute the total payoff $v(N)$ that is available to the participants in this coalition N. Note that under the assumption of a convex game, the formation of a grand coalition N is the most rational outcome. Therefore, such a characteristic function induces all participants to take part in a cooperative effort in order to increase the payoff of every participant. Furthermore, as discussed by Sherali and Rajan (1986), while supperadditivity ensures that the total payoff is a maximum for the grand coalition and admits a distribution satisfying (3.1) and (3.2), it does not necessarily imply that a grand coalition would be the most rational emerging coalition. The reason for this is that unlike as in the case of convex games, it does not preclude the possibility of particular players within other subcoalitions from enjoying greater payoffs.

Definition 3.10 (Shapley, 1971): Given distributions $\boldsymbol{x}$ and $\boldsymbol{y}$, and a coalition $S \subseteq N$, $\boldsymbol{x}$ is said to be *superior* to $\boldsymbol{y}$ on S, denoted $\boldsymbol{x} \succ_S \boldsymbol{y}$, if

$$x_i \geq y_i, \forall i \in S \text{ (with at least one inequality strict)}$$

and

$$\sum_{i \in S} x_i \leq v(S). \tag{3.3}$$

A distribution $\boldsymbol{x}$ satisfying Inequality (3.3) is called a *feasible distribution* for the coalition S.

Definition 3.11 (Shapley, 1971): For an n-player cooperative game (N, v), the nondominated distributions in $E(v)$, that is, the distributions for which there does not exist any other superior distribution with respect to any coalition $S \subseteq N$, is called the *core* of the game. Hence, the core, denoted $C(N, v)$, is composed of all payment vectors satisfying

$$\sum_{i \in S} x_i \geq v(S), \forall S \subseteq N \tag{3.4}$$

$$\sum_{i \in N} x_i = v(N). \tag{3.5}$$

Relation (3.4) is called the coalition rational condition, analogous to the special case of the individual rational condition (3.1).

3.2 A Mechanism to Induce Regional Technological Cooperation

Obviously, the core is a closed convex set. If the core of a game is non-empty, such as when the game is convex (Shapley, 1971), the total payoff $v(N)$ available to a grand coalition can be distributed to each player in a manner such that this type of distribution method satisfies not only the individual rational condition and the collective rational condition, but also the coalition rational condition. Namely, what any subset of players $S \subseteq N$ gains under this type of a distribution is not less than the payoff that this coalition S could have received had it acted independently. Conversely, if a feasible distribution $\boldsymbol{x}$ is not in the core, there exists a coalition $S \subseteq N$ for which the players in Coalition S can distribute the value $v(S)$ available though their independent cooperation, so that the resulting distribution is superior to distribution $\boldsymbol{x}$ on S. Therefore, a distribution that belongs to the core can be rationally accepted by all the players in the grand coalition N.

Note that there might exist several rational methods for distributing the payoff of a coalition. Needless to say, such a distribution is not necessarily based on an average allocation. One eminently appealing concept whereby the distribution is determined by means of a weighted average of the marginal contribution that each player brings to every possible coalition, leads to the so-called Shapley value distribution mechanism.

Lemma 3.1 (Shapley, 1971): A type of feasible distribution plan for allocating the payoff $v(N)$ of the grand coalition N is

$$x_i \equiv \varphi_i(N,v) = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{(|S|-1)!(n-|S|)!}{n!}[v(S) - v(S-\{i\})], \forall i = 1,\cdots,n \tag{3.6}$$

where $|S|$ denotes the cardinality of the coalition $S \subseteq N$. (The collection $\{\varphi_i(N,v)\}_{i\in N}$ is called a set of *Shapley Values.*)

Lemma 3.2 (Shapley, 1971): If (N,v) is a convex game, then $\{\varphi_i(N,v)\}_{i\in N} \in C(N,v)$.

Lemma 2 indicates that if the regional technological cooperative game is convex, then the Shapley allocations given by (3.6) belong to the core, and hence satisfy the desirable rationality conditions (3.4) and (3.5).

We now describe a characteristic function for a regional technological cooperative game, wherein each participant is viewed as a player whose strategy is its national technology transfer ability and level, and establish that the underlying game is convex.

A two-country case for cooperative behavior in which the countries could derive both common as well as different benefits was discussed in Peter (1993). The benefit allocation relationship between the two countries was represented in a two-dimensional space by a set of discrete points, where each point in the space delineated a possible combination of utilities. Viewing this example from our perspective, the decisions faced by these two countries would concern not only the question of whether or not they should cooperate, but also the question as to how they should redistribute the benefits if they do cooperate, and what cooperative strategies should they adopt.

Generally, $v(S)$, $\forall S \subseteq N$ is called the worth of Coalition S. For any coalition $S \subseteq N$ and each player $i \in S$, we can formulate $v(S)$ based on the following four conceptual components. First, before any utility is transferred, player i has the reservation utility R_0^i, that is due to its technical ability and level in isolation, before taking part in any form of cooperation or interactions in the global market. One method of quantifying this is to use the related evaluation targets in recent years (World Economic Forum, 1998). Second, under the concept of a grand coalition, we define K_j^i as the payoff or benefit that player i receives due to the presence of each player $j \in N$, $j \neq i$, taking part in the cooperation (Yin, 1993). In the case of the regional technological cooperation game, K_j^i represents the increase and enhancement of player i's technical ability and level, which come from the activities and effects of technology transfer due to the progress and dissemination effects of player j being part of its coalition. The next two components occur as a result of adjustments in the foregoing utility transfer for each $i \in S$ due to player j in $N - S$ not taking part in coalition S. The first of these represents the loss of player $i \in S$ based on each player $j \in N - S$ that does not take part in Coalition S, and the other component represents any gain that player i might derive from each of the players $j \in N - S$, despite their not being a formal part of coalition S. Accordingly, for each $i \in S$ and $j \in N - S$, let δ_j^i be the reduction in the benefit or payoff of player i which comes from the loss of the direct benefits due to player j not being a part of Coalition S, and let π_j^i be the increment in the direct payoff of player i due to any interactions it might have with player j outside the framework of a formal coalition. Note that this allows for somewhat more general compensations and interaction effects than simply letting $\delta_j^i \equiv K_j^i$ and $\pi_j^i \equiv 0$, $\forall i \neq j$. Naturally, we can also assume the following to hold true:

$$\beta_j^i \equiv \delta_j^i - \pi_j^i \geq 0, \ \forall i \in S, j \in N - S. \qquad (3.7)$$

In the context of regional technological cooperation, if player i is one of the participants receiving the new technology in the technology transfer process, δ_j^i is generally determined by the following economic factors.

(i) Competitiveness and profitability of businesses;
(ii) new products and services;
(iii) nation's base of technical knowledge;
(iv) research, development and procurement costs;

(v) return on engineering, research and development investments;
(vi) access to industry expertise;
(vii) overall system performance, and
(viii) creation of skilled and high paying jobs.

Correspondingly, for this case, the entity π_j^i is generally determined by the following economic factors.

(i) Opportunity to acquire the new technology, and
(ii) general availability of some products, technical information, and services.

If player i is one of the participants holding the new technology in the technology transfer process, δ_j^i is generally determined by the following economic factors.

(i) Competitiveness and profitability of businesses;
(ii) economic advantages through delayed trade and continued development;
(iii) geopolitical benefits;
(iv) expanded opportunities for development;
(v) opportunities for jobs and low cost labor, and
(vi) market access for selling the technology.

Similarly, for this case, the entity π_j^i is generally determined by the following economic factors.

(i) Opportunity to unilaterally sell technology, and
(ii) transfer of related products, information, and services via open conduits and markets.

From the foregoing discussion (see Myerson, 1991, and Von Neumann and Morgenstern, 1953, for further details), we can formulate the following characteristic function for a regional technological cooperative game.

$$v(S) = \sum_{i \in S} \{\alpha^i - \sum_{j \in N-S} \beta_j^i\}, \forall S \subseteq N \tag{3.8a}$$

where

$$\alpha^i \equiv R_0^i + \sum_{\substack{j \in N \\ j \neq i}} K_j^i, \forall i \in N \text{, and } \beta_j^i \equiv \delta_j^i - \pi_j^i, \ \forall i \in S, j \in N-S. \tag{3.8b}$$

Note that for each participant i in the coalition S, the first term α^i in the summand in (3.8a) is the reservation utility of i before taking part in any form of cooperation or interactions with the other players, plus the sum of the payoffs gained due to the other players when forming the grand coalition N. The second term β_j^i in the summand in (3.8a) is the net loss (noting (3.7)) that adjusts the foregoing term based on the players in $N-S$ not taking part in coalition S. This is comprised of a direct loss component δ_j^i minus the payoff π_j^i based on any unilateral cooperation of player i with each of the other players j in $N-S$. Observe that $v(S)$ for any $S \subset N$ (and $v(\{i\})$ in particular), depends on the other players $j \in N-S$ because of the interactions due to a global market. That is, $v(S)$ does not simply depend on the actions and influences of the players within S itself in isolation. This is similar in concept to the characteristic functions defined for oligopolistic markets by Sherali and Rajan (1986).

Theorem 3.1. The regional technological cooperative game defined by (3.8a) is convex.

Proof: For each player $i \in N$, and for all $S \subseteq T \subseteq N-\{i\}$, we get from (3.8a) that

$$v(S \cup \{i\}) = [v(S) + \sum_{j \in S} \beta_i^j] + [v(i) + \sum_{j \neq i} \beta_j^i] - \sum_{\substack{j \notin S \\ j \neq i}} \beta_j^i \ .$$

Combining terms,

$$v(S \cup \{i\}) = v(S) + v(i) + \sum_{j \in S} (\beta_i^j + \beta_j^i) \, ,$$

or that,

$$v(S \cup \{i\}) - v(S) = v(i) + \sum_{j \in S} (\beta_i^j + \beta_j^i) \, . \tag{3.9}$$

Similarly, we have

$$v(T \cup \{i\}) - v(T) = v(i) + \sum_{j \in T} (\beta_i^j + \beta_j^i) \ .$$

Because $S \subseteq T$, and from (3.7) we have $\beta_j^i \geq 0$ and $\beta_i^j \geq 0$, we get

$$\sum_{j \in S} (\beta_i^j + \beta_j^i) \leq \sum_{j \in T} (\beta_i^j + \beta_j^i) \, .$$

Therefore,

$$v(S \cup \{i\}) - v(S) \leq v(T \cup \{i\}) - v(T) \, .$$

This completes the proof. □

Because the technical ability and level of each participant is different, the utility for each participant to take part in cooperation is different. Each participant must inherit a rational payoff compensation for the cooperation to be stable. If the final payoff of the cooperation is distributed by the Shapley Value, then since this distribution belongs to the core because the game is convex (see Lemma 3.2 and Theorem 3.1), we will have prescribed a rational transfer mechanism among the participants. A closed-form expression for this rational transfer quantity is derived by the following result.

Theorem 3.2. For the defined regional technological cooperative game (N,v), where v is given by (3.8a), the Shapley Value allocation is given by

$$\varphi_i(N,v) = \alpha^i + \frac{1}{2}\sum_{\substack{j=1\\ j\neq i}}^{n}(\beta_i^j - \beta_j^i)\text{, for } i = 1,\cdots,n. \tag{3.10}$$

Proof: By Equation (3.9) and Formula (3.6), the Shapley allocation for any $i\in N$ is given by

$$\varphi_i(N,v) = \sum_{\substack{S\subseteq N\\ i\in S}}\frac{(|S|-1)!(n-|S|)!}{n!}[v(i)+\sum_{\substack{j\in S\\ j\neq i}}(\beta_i^j+\beta_j^i)]$$

$$= v(i) + \sum_{\substack{j=1\\ j\neq i}}^{n}(\beta_i^j+\beta_j^i)\sum_{\substack{S\subseteq N\\ i,j\in S}}\frac{(|S|-1)!(n-|S|)!}{n!}$$

where

$$\sum_{\substack{S\subseteq N\\ i\in S}}\frac{(|S|-1)!(n-|S|)!}{n!} = \sum_{s=1}^{n}\sum_{\substack{S\subseteq N\\ i\in S\\ |S|=s}}\frac{(s-1)!(n-s)!}{n!} = \sum_{s=1}^{n}\frac{(s-1)!(n-s)!}{n!}\times\frac{(n-1)!}{(s-1)!(n-s)!} = 1.$$

Similarly, note that

$$\sum_{\substack{S\subseteq N\\ i,j\in S}}\frac{(|S|-1)!(n-|S|)!}{n!} = \sum_{s=2}^{n}\sum_{\substack{S\subseteq N\\ i,j\in S\\ |S|=s}}\frac{(s-1)!(n-s)!}{n!}$$

$$= \sum_{s=2}^{n}\frac{(s-1)!(n-s)!}{n!}\times\frac{(n-2)!}{(n-s)!(s-2)!} = \frac{1}{2}.$$

Therefore, we have

$$\varphi_i(N,v) = v(i) + \frac{1}{2}\sum_{\substack{j\in N\\ j\neq i}}(\beta_i^j+\beta_j^i). \tag{3.11}$$

But from Equation (3.8a), we have

$$v(i) = \alpha^i - \sum_{\substack{j \in N \\ j \neq i}} \beta_j^i \, . \tag{3.12}$$

Hence, using (3.12) and (3.11), we get

$$\varphi_i(N, v) = (\alpha^i - \sum_{\substack{j \in N \\ j \neq i}} \beta_j^i) + \frac{1}{2} \sum_{\substack{j \in N \\ j \neq i}} (\beta_i^j + \beta_j^i) = \alpha^i + \frac{1}{2} \sum_{\substack{j \in N \\ j \neq i}} (\beta_i^j - \beta_j^i) \, .$$

This completes the proof. □

Observe that if we ignore any transferable utility, then the payoff for player i in the grand coalition N is α^i. Indeed, from (3.8a), we have that the total payoff for the grand coalition N is

$$v(N) = \sum_{i \in N} \alpha^i \, . \tag{3.13}$$

However, since we have transferable utility, the payoff for player i in the grand coalition N is adjusted as per the Shapley value (3.10). Therefore, the difference between this value in Equation (3.10) and α^i is the amount of transferable utility that is distributed by the Shapley value allocation for each $i \in N$, and is given by

$$T_i = \frac{1}{2} \sum_{\substack{j=1 \\ j \neq i}}^{n} (\beta_i^j - \beta_j^i) \text{, for } i = 1, \cdots, n \, . \tag{3.14}$$

Moreover, the difference between Equation (3.10) and the reservation utility R_0^i of player i that is realized if i is in isolation is the overall payoff or inducement for player i that accrues from the regional technological cooperative game in the global market with transferable utility. This "inducement" factor is given by

$$I_i \equiv \sum_{\substack{j=1 \\ j \neq i}}^{n} K_j^i + \frac{1}{2} \sum_{\substack{j=1 \\ j \neq i}}^{n} (\beta_i^j - \beta_j^i) \text{, for } i = 1, \cdots, n \, . \tag{3.15}$$

In the practice of regional technological cooperation, the quantity in (3.15) must be nonnegative (preferably positive) for each player i, since this expression represents in effect the inducement or motivation for player i to take part in this cooperative effort. Since the game is convex, we have that the grand coalition emerges and that the Shapley value allocation belongs to the core, thereby lending rationality to the transfer quantities $T_i, \forall i$, given by (3.14). Note that β_i^j is the net reduction in payoff for j if i does not coalesce with it, and β_j^i is the net reduction in payoff for i under this same condition. The transferable utility T_i that is distributed by the Shapley value allocation is half the sum of the difference between these two entities over all the other players in $N-\{i\}$. As a consequence of this allocation scheme, the countries that gain more benefit give a compensation to the countries that gain less benefit. There are many reasons why Country j might gain more benefit than Country i via a regional technological cooperation, and hence induce such a compensation scheme. For example, Country j might have a greater need for the technology of Country i than conversely, or Country j might have a greater relative ability to generate some common technology due to its cooperation with Country i than vice versa. At the same time, after the former countries provide such a compensation to the latter countries, their welfare should be higher than that of their assumed reservation utility in isolation, i.e., (3.15) should be positive. In this manner, a cooperative agreement can be reached, or a mutually beneficial undertaking can be made.

In practice, because there are many factors that influence the benefit of every participant, the characteristic function in Formula (3.8a) should be carefully crafted based on tangible economic factors from among the ones outlined above, and the payoff compensation or allocation scheme in Formula (3.10) should probably be combined with other compensation mechanisms.

If all players take part in cooperation without transferable utility, then we have

$$v(S)=\sum_{i\in S}\{\alpha^i\},\forall S\subseteq N \tag{3.8c}$$

Comparing Formula (3.8c) with Formula (3.8a), we have

Corollary: When all players take part in cooperation, the regional technological cooperation without transferable utility is in core if and only if

$$v(S)=\sum_{i\in S}\{\alpha^i\}\geq\sum_{i\in S}\{\alpha^i-\sum_{j\in N-S}\beta^i_j\},\forall S\subseteq N$$

that is

$$\sum_{i\in S}\sum_{j\in N-S}\beta^i_j\geq 0,\forall S\subseteq N\,. \tag{3.16}$$

When all the players have the same technological level, Formula (3.16) is $s(n-s)\delta\geq s(n-s)\pi$. Therefore, the transferable utility is not necessary when the players with the same (or almost same) technological level take part in regional technological cooperation.

3.3 Illustrative Examples

For the sake of illustration, consider a scenario involving three countries (indexed $i = 1,2,3$, with $N = \{1,2,3\}$). For example, this might refer to home-used electrical manufacturing industries in Japan ($i = 1$), The Republic of Korea ($i = 2$), and China ($i = 3$). Suppose that the data is specified as in Table 1 for a base-case scenario, where the units are some scaled commensurate monetary quantities. The relevant computations leading to the Shapley value allocations given by Equation (3.10) and the inducement factors given by Equation (3.15) are displayed in Table 2. We can see that the reservation utility of i before taking part in any form of cooperation is 10, 4, and 1, for $i = 1$, 2, and 3, respectively. After forming the grand coalition, and without any utility transfer, the payoffs for the countries $i = 1$, 2, and 3, are respectively12, 8, and 8. However, when there is utility transfer, these payoffs are adjusted by the Shapley value allocations to the respective values 12.5, 8.5, and 7 (0.5 from player 3 to player 1 and 0.5 from player 3 to player 2). The quantities 2.5, 4.5, and 6, respectively, represent in effect the inducement or motivation for the players to take part in this cooperative effort.

Table 3.1. Base-Case Scenario Data.

i	R_0^i	K_j^i for $j \neq i$			δ_j^i for $j \neq i$			π_j^i for $j \neq i$		
		$j=1$	$j=2$	$j=3$	$j=1$	$j=2$	$j=3$	$j=1$	$j=2$	$j=3$
1	10	-	1	1	-	1	1	-	0	0
2	4	3	-	1	2	-	1	1	-	0
3	1	4	3	-	3	3	-	1	1	-

Table 3.2. Results for the Base-Case.

i	α^i (Eqn (3.8b))	β_j^i for $j \neq i$ (Eqn (3.8b))			Shapley Values φ_i (Eqn (3.10))	Inducement Factors I_i (Eqn(3.15))
		$j=1$	$j=2$	$j=3$		
1	12	-	1	1	12.5	2.5
2	8	1	-	1	8.5	4.5
3	8	2	2	-	7	6

Next, let us consider the special case in which the net reduction in benefit δ_j^i for player i when j is not a part of its coalition is K_j^i itself, with no extraneous interaction impact accruing (i.e., $\pi_j^i \equiv 0$), $\forall i, j$. Then, with the reservation utilities $R_0^i, \forall i$, and the cooperation benefits

$K_j^i, \forall i \neq j$, being as given in Table 3.1, we obtain the results presented in Table 3.3. In this case, after forming the grand coalition and effecting utility transfer via the Shapley value allocations, the payoffs for players $i = 1$, 2, and 3 become 14.5, 8, and 5.5, respectively. Noting the α^i values, there is a net utility transfer of 2.5 from player 3 to player 1. The quantities 4.5, 4, and 4.5 respectively represent the inducement or motivation for the players to take part in this cooperative effort. By comparing these results with those given in Table 3.2, we notice that because of the complete loss of related benefits whenever a player is not part of a coalition, given the relative contributions reflected by the K_j^i values in Table 3.1, the Shapley value allocation of player 1 is further boosted in the present case, and the inducement factors have become more balanced as well.

Table 3.3. Results for the Base-Case Variation in which $\delta_j^i = K_j^i$ and $\pi_j^i \equiv 0, \forall i \neq j$.

i	α^i (Eqn (3.8b))	β_j^i for $j \neq i$ (Eqn (3.8b))			Shapley Values φ_i (Eqn (3.10))	Inducement Factors I_i (Eqn(3.15))
		$j=1$	$j=2$	$j=3$		
1	12	-	1	1	14.5	4.5
2	8	3	-	1	8	4
3	8	4	3	-	5.5	4.5

Finally, consider the situation in which the data is as specified in Table 1, except that the reservation utility $R_0^i \equiv 5, \forall i = 1,2,3$ (the average value of the reservation utilities given in Table 1). For example, in the case of the coalition for home-used electrical manufacturing industries formed by Japan ($i = 1$), The Republic of Korea ($i = 2$), and China ($i = 3$), the base-case data for the reservation utilities might be more indicative of the situation about a decade ago, while the values assumed presently are somewhat more contemporary. However, let us assume hypothetically that the relative benefits of cooperation are as disparate as specified in Table 1. The results obtained in this case are displayed in Table 4. We can see that after forming the grand coalition, and when there is no utility transfer, the payoffs for the three players are given by 5, 9, and 12, respectively. These payoffs are adjusted to the values 5.5, 9.5, and 11 when there is utility transfer (0.5 from player 3 to player 1 and 0.5 from player 3 to player 2), by virtue of the Shapley value allocations. The quantities 0.5, 4.5, and 6 respectively represent the inducement or motivation for the players to take part in this cooperative effort. By comparing these results with those given in Table 2, we notice that in the present case, players 2 and 3 continue to derive strong synergistic benefits in the presence of player 1, while their reservation utilities are similar. Hence, the Shapley value allocations for players 2 and 3 have increased (more so for player 3), while the Shapley allocation, and hence inducement, for player 1 to participate in this grand coalition has further diminished.

Table 3.4. Results for the Base-Case Variation in which $R_0^i \equiv 5, \forall i$.

i	α^i (Eqn (3.8b))	β_j^i for $j \neq i$ (Eqn (3.8b))			Shapley Values φ_i (Eqn (3.10))	Inducement Factors I_i (Eqn(3.15))
		$j=1$	$j=2$	$j=3$		
1	5	-	1	1	5.5	0.5
2	9	1	-	1	9.5	4.5
3	12	2	2	-	11	6

Chapter 4

Approach for Analyzing Foreign Direct Investment Projects with Application to China's Tumen River Area Development

In this Chapter, we discuss the various modules that describe the methodological framework of a Project Evaluation Model (see Figure 4.1). The project database contains information regarding the different technical, economic, social, and political aspects of the various projects. Section 4.1.1 defines and discusses the target system, and Section 4.1.2 describes the computations involved in the evaluation submodel. The expert system input required for this phase is described in Section 4.1.3. The results from this analysis are fed into a simulation submodel which is discussed in Section 4.1.4. Finally, details of the overall iterative process and the output results are provided in Section 4.2.

4.1 Construction of a General Model

The structure and framework of a comprehensive project evaluation model that is proposed in this Chapter is depicted in Figure 4.1. Its focal viewpoint is to capture the perspective of foreign investors whose aim is to comprehensively investigate the various projects. The process embodied in this framework is different from traditional approaches for evaluating projects. The intent is not merely to choose the best among projects arising within some micro-enterprise, nor is it to choose the best among projects pertaining to several enterprises with regard to some macro-strategy. Rather, the thrust here is to conduct a comprehensive fuzzy evaluation of the projects by using the principles of modern system theory and information theory. The approach is "comprehensive" in that the project evaluation process includes not only the economic analysis of individual projects, but also the consideration of several factors and conditions that influence and interrelate the assessment of these projects. It is "fuzzy" in that the evaluation targets or criteria that are identified for comprehensively analyzing the projects have both qualitative and quantitative inputs. Since it is difficult to describe such evaluation targets or objective criteria with precise numbers, this task can be handled best by fuzzy decision methods (Roy 1990 and Stewart 1992).

4.1.1. Target system

The target system is a structural framework that defines the objectives of the evaluation process. The identification of the targets and their quantification are the two defining components of this system (Saaty 1980, 2000). Usually, the target system is of paramount importance in the project evaluation process because it dictates the standards, rules, and decision outcomes that result from this process. For example, the economic income and the location chosen for the projects might be influenced by the objectives that define the target system.

4.1.1.1. Definition of the target system: criterion principles for evaluating the projects

Foreigners investing in other countries care very much about the direct profit they can acquire and the potential for future profit realization. These two factors constitute two principal criteria for evaluating the various projects. The direct profit factor is inherent within the project itself and is easy to identify, but the potential for future profit realization is multi-sided and more complex. In this Thesis, we only consider issues related to commercial risks in defining the latter factor. In general, there are some fundamental guiding principles that serve to identify a target system. These principles can be delineated as follows.

(1) The target system should generally reflect factors that foreign investors can study and evaluate.
(2) The target system should focus on certain key influencing factors.
(3) The targets should be comparable. That is, it must be possible to evaluate each project in terms of the targets in a uniform fashion that permits their subsequent comparison.
(4) The qualitative factors governing the targets should be classifiable into several grades so as to be comparable and permit an appropriate quantification of the target values.

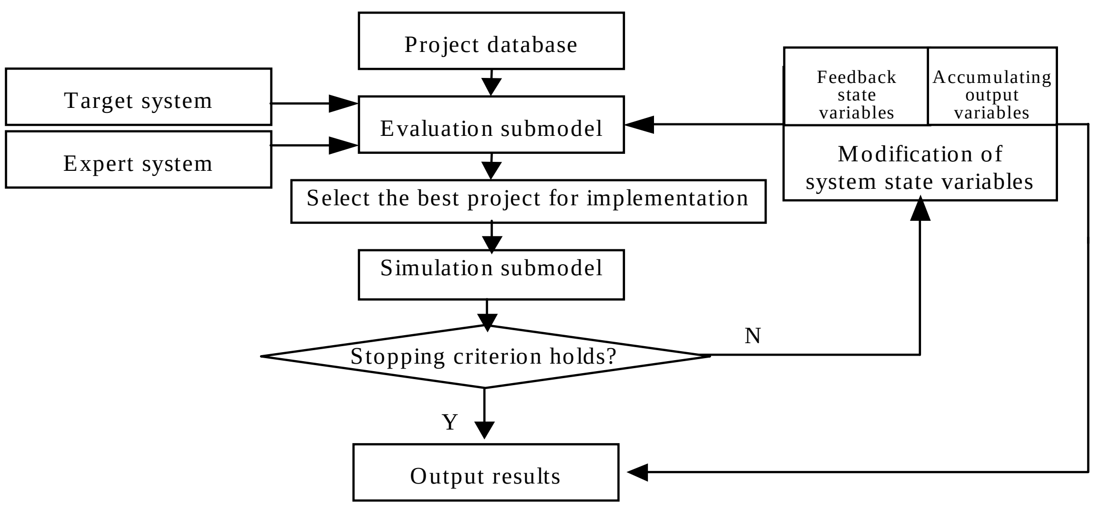

Figure 4.1. The Structure and Functional Framework of the Projects Evaluation Model.

4.1.1.2. Identification of the target system used in this study for evaluating projects

The target system used in this study has a four-level structure and is based on the aforementioned two criteria related to direct profits and the potential for future profit realization. The structural framework of this target system is shown in Figure 4.2, and is described in detail below. The twelve fourth-level characteristics constitute the principal evaluation targets based on which foreign investors can assess the various available projects.

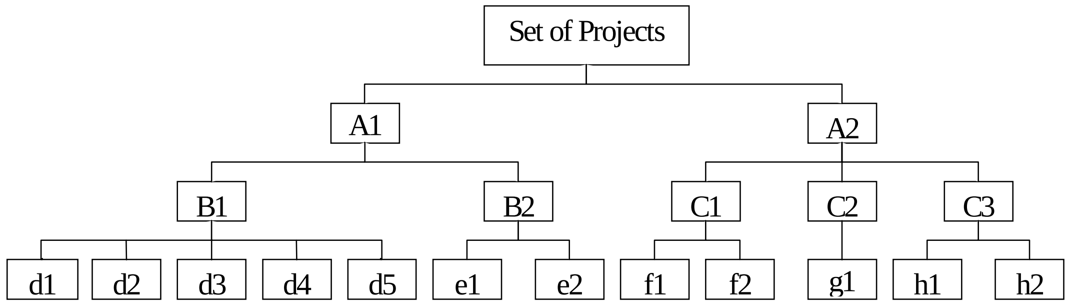

Figure 4.2. The Structural Framework for the Proposed Target System for Evaluating Projects.

(1) A1 - Target system representing direct profits:

(i) B1 - Internal economic evaluation of the project

d1 - Net present value rate
d2 - Internal rate of return
d3 - Investment return rate
d4 - Investment recovery period
d5 - Total investment amount.

(ii) B2 - External economic evaluation of the project:

e1- Industry investment density of the project. (This quantity is equal to the total industry investment amount divided by the total regional population. Given a stable regional population in the area in recent years, this ratio is governed mainly by the total industry investment amount. For evaluation purposes, we take the net present value of the fixed assets as the total industry investment amount in the formula.)

e2 - Industrial investment profit rate of the project. (This quantity is equal to the total industry profit amount divided by the total industry investment amount. Its basic purpose is to classify the investment amounts that constitute the above target (e1) into different ranges based on their related profitabilities, so as to reflect foreign investors' investment preferences.)

(2) A2 - Target system representing the potential for future profit realizations:

(i) C1 - Construction conditions:

f1 - Government funding class. (This is a qualitative target, and classifies each project as a local (county or city), regional, provincial, or national project. Each of these governmental levels of funding is assigned different evaluating values by the expert system discussed below in Section 2.3.)

f2 - Construction location. (This qualitative criterion distinguishes between the local infrastructure and the transportation conditions of eight cities in the area that are concerned with the different projects. Different locations are ascribed different evaluation values.)

(ii) C2 - Production condition:

g1 - Condition for supplying raw material. (This is a qualitative target. We can classify it into several types by considering the relative ease with which the raw material can be acquired and locally processed. Depending on whether it is available locally, from the province, available from other areas in China, or it is necessary to obtain it from first grade imports, we ascribe different evaluation values.)

(iii) C3 - Product and market:

h1 - Dominant degree of the product. (This is another qualitative target. Here, we evaluate the dominant degree of the product with respect to its design and manufacturing technology in comparison with similar characteristics of this type of product that is produced elsewhere in the region, the province, the nation, and in the world. The more dominant the product is, the more easily the market will accept the product.)

h2 - Market demand of the product. (This is also a qualitative target used to explain the market condition of the product.)

4.1.2. Evaluation Submodel

Let the set of projects be indexed by i, for $i = 1, \cdots, m$. In the present study, we have $m = 103$. Then, the following evaluation matrices characterize the projects with respect to the target system described in the foregoing section.

$$\overline{B}_1 = \begin{bmatrix} d_{1,1} & \cdots & d_{1,5} \\ \vdots & \ddots & \vdots \\ d_{m,1} & \cdots & d_{m,5} \end{bmatrix},\ \overline{B}_2 = \begin{bmatrix} e_{1,1} & e_{1,2} \\ \vdots & \vdots \\ e_{m,1} & e_{m,2} \end{bmatrix}, \overline{C}_1 = \begin{bmatrix} f_{1,1} & f_{1,2} \\ \vdots & \vdots \\ f_{m,1} & f_{m,2} \end{bmatrix}, \overline{C}_2 = \begin{bmatrix} g_1 \\ \vdots \\ g_m \end{bmatrix}, \overline{C}_3 = \begin{bmatrix} h_{1,1} & h_{1,2} \\ \vdots & \vdots \\ h_{m,1} & h_{m,2} \end{bmatrix} \quad (4.1)$$

where, as per Figure 4.2 and the discussion in Section 2.1.2, $\overline{B}_1$ is an $m \times 5$ matrix that records the evaluating values of the five internal economic target criteria d1, d2, d3, d4, and d5 in the respective columns $1, \cdots, 5$ for the set of m projects, and similarly, $\overline{B}_2$ is an $m \times 2$ matrix that records the evaluating values of the external economic factors e1 and e2 for the various projects, $\overline{C}_1$ is an $m \times 2$ matrix that records the evaluating values of the construction conditions f1 and f2 for the different projects, $\overline{C}_2$ is an $m \times 1$ matrix that contains the evaluating values of the production condition (raw material supply status) g1 for the various projects, and $\overline{C}_3$ is an $m \times 2$ matrix that records the evaluating values of the product domination and market demand indices h1 and h2, respectively, for the different projects. (Section 4.1.3 describes how the different elements of these matrices are quantified numerically.)

Now, let us define weights to reflect the relative importance of the various fourth-level evaluation criterion that characterize each of B1, B2, C1, and C3, (see Figure 4.2; also, note that C2 is associated only with the single criterion g1). For example, we define a weight vector for the fourth-level targets associated with B1 as $w_{B1\sim d}$, having components $w_{B1\sim d1}$, $w_{B1\sim d2}$, $w_{B1\sim d3}$, $w_{B1\sim d4}$, and $w_{B1\sim d5}$ (summing to 1) that respectively represent the relative weights ascribed to the criteria d1, d2, d3, d4, and d5. Similarly, we define the relative weight vectors $w_{B2\sim e}$, $w_{C1\sim f}$, $w_{C2\sim g} \equiv 1$ (because C_2 has a single criterion), and $w_{C3\sim h}$, yielding the following. The actual computation of these weights is described in Section 4.1.3.

$$w_{B1\sim d} = \begin{bmatrix} w_{B1\sim d1} \\ w_{B1\sim d2} \\ w_{B1\sim d3} \\ w_{B1\sim d4} \\ w_{B1\sim d5} \end{bmatrix},\ w_{B2\sim e} = \begin{bmatrix} w_{B2\sim e1} \\ w_{B2\sim e2} \end{bmatrix},\ w_{C1\sim f} = \begin{bmatrix} w_{C1\sim f1} \\ w_{C1\sim f2} \end{bmatrix},\ w_{C2\sim g} = [1], \text{ and } w_{C3\sim h} = \begin{bmatrix} w_{C3\sim h1} \\ w_{C3\sim h2} \end{bmatrix}. \quad (4.2)$$

Accordingly, using these weights, we can derive *aggregate evaluation vectors* for the set of m projects as follows from Equations (4.1) and (4.2).

$$V_{B1} = \overline{B}_1 \cdot w_{B1\sim d},\ V_{B2} = \overline{B}_2 \cdot w_{B2\sim e},\ V_{C1} = \overline{C}_1 \cdot w_{C1\sim f},\ V_{C2} = \overline{C}_2, \text{ and } V_{C3} = \overline{C}_3 \cdot w_{C3\sim h} \quad (4.3)$$

where,

V_{B1}: Vector of aggregated values for the internal economic target indices for the m projects;
V_{B2}: Vector of aggregated values for the external economic target indices for the m projects;
V_{C1}: Vector of aggregated values for the construction condition indices for the m projects;
V_{C2}: Vector of values for the production indices for the m projects; and
V_{C3}: Vector of aggregated values for the product and market indices for the m projects.

Likewise, we can define suitable corresponding weight vectors to reflect the relative importances of the third-level aggregated criteria under each of the headings A1 and A2 as follows.

$$w_{A1\sim B} = \begin{bmatrix} w_{A1\sim B1} \\ w_{A1\sim B2} \end{bmatrix} \text{ and } w_{A2\sim C} = \begin{bmatrix} w_{A2\sim C1} \\ w_{A2\sim C2} \\ w_{A2\sim C3} \end{bmatrix}. \quad (4.4)$$

Accordingly, this yields from Equations (4.3) and (4.4)

$$V_{A1} = [V_{B1},\quad V_{B2}] \cdot w_{A1\sim B} \text{ and } V_{A2} = [V_{C1},\quad V_{C2},\quad V_{C3}] \cdot w_{A2\sim C} \quad (4.5)$$

where,

V_{A1}: Vector of aggregated values for the direct profit target indices for the m projects, and
V_{A2}: Vector of aggregated values for the future profit realization potential for the m projects.

Finally, denoting w_{A1} and w_{A2} as suitable relative weights ascribed to the principal targets A1 and A2, we get

$$V = [V_{A1}, \quad V_{A1}] \cdot \begin{bmatrix} w_{A1} \\ w_{A2} \end{bmatrix} \equiv \begin{bmatrix} v_1 \\ \vdots \\ v_m \end{bmatrix}, \tag{4.6}$$

where v_i represents the overall comprehensive evaluating value for assessing the worth of the project i, for $i = 1, \cdots, m$, and where V is the vector of these values. These indices v_i provide a basis for ranking the projects as discussed in the sequel.

4.1.3. Expert System

Since a target system concerns certain qualitative targets, and the aggregation of attributes at various levels of the target system requires certain weights in order to compute the evaluation indices for the different projects, we used an expert group's knowledge, wisdom, experience, intuition, inference, preference, and value-view to derive such weights. Furthermore, it is also necessary to transform the values and attributes of the fourth-level quantitative and qualitative targets in Figure 4.2 to commensurate *evaluation scores* by using the experts' judgment in order to assess the matrices (4.1) for use in deriving (4.6).

We discuss the expert system used in this study and the Analytic Hierarchy Process (AHP) method in Section 4.1.3.1. The expert system resolves two principal issues: one is concerned with determining the relative weight distributions for each group of targets at each level in Figure 2, and the other is concerned with determining comparable and consistent evaluation scores for the targets at the fourth-level. This latter scoring mechanism for both quantitative as well as qualitative fourth-level targets is discussed in Section 4.3.1.2.

4.1.3.1. Expert System and the Analytic Hierarchy Process (AHP)

In this thesis, the AHP method (Satty 1980, 2000) is adopted to derive the required relative weights for the targets at the different levels in Figure 4.2. The principal steps in this process are to first compare pairs of related targets at the same level so that we can derive the basic judgment matrices, and second, to compute the relative weight values pertaining to the groups of targets as required in Equations (4.2) – (4.6) (Zahedi 1986). In order to obtain the experts' judgment matrix, the experts were queried twice during the study. This query process involved having a set of experts respond to questionnaires regarding pairwise comparisons of targets, as well as a subsequent discussion among another set of experts. The questionnaire responses were obtained from eight municipal officials, six project directors, one Chinese expert, three international experts, and two officials of UNIDO. (These individuals composed the preparatory committee of the " *'95 China's Tumen River Area International Investment and Business Forum*".) The expert discussion group involved eight scholars and researchers of the Tumen River Development program. (This group composed the academic committee of the " *'95 China's Tumen River Area International Investment and Business Forum*".) These experts screened the inputs provided via the questionnaires and eliminated the obviously wrong answer sheets. Altogether, seventeen questionnaires were accepted (five from municipal officials, six from project directors, four from UNIDO experts, and two from UNIDO officials). By analyzing these questionnaires, we derived the relative weight vectors for the targets using the AHP method (Zahedi 1986), applied the (stochastic) unanimity test (Dai 1994), and finally, obtained an agreement of the experts on the resulting weight vectors derived for the target system. This process yielded the following relative target weights for use in Equations (4.3), (4.5), and (4.6).

$$w_{B1\sim d} = \begin{bmatrix} 0.1665 \\ 0.1821 \\ 0.2667 \\ 0.0001 \\ 0.3846 \end{bmatrix},\ w_{B2\sim e} = \begin{bmatrix} 0.6257 \\ 0.3743 \end{bmatrix},\ w_{C1\sim f} = \begin{bmatrix} 0.6072 \\ 0.3928 \end{bmatrix}, w_{C3\sim h} = \begin{bmatrix} 0.3441 \\ 0.6559 \end{bmatrix},$$

$$w_{A1\sim B} = \begin{bmatrix} w_{A1\sim B1} \\ w_{A1\sim B2} \end{bmatrix} = \begin{bmatrix} 0.4355 \\ 0.5645 \end{bmatrix}, w_{A2\sim C} = \begin{bmatrix} w_{A2\sim C1} \\ w_{A2\sim C2} \\ w_{A2\sim C3} \end{bmatrix} = \begin{bmatrix} 0.2123 \\ 0.4246 \\ 0.3631 \end{bmatrix},\ w_A = \begin{bmatrix} w_{A1} \\ w_{A2} \end{bmatrix} = \begin{bmatrix} 0.6675 \\ 0.3325 \end{bmatrix}. \qquad (4.7)$$

4.1.3.2. The Principle and Procedure for Quantifying the Fourth-Level Targets

To ensure that the fourth-level targets in Figure 4.2 can be compared with each other and are objectively consistent, we must translate the assessment of each of these targets into some common evaluation measure (see Dai 1994). The following subsections describe the procedure used to ascribe such *evaluation scores* for each of the fourth-level targets. The scores derived by this process are all on a scale of [1, 10], and are then used to define the evaluation matrices in Equation (1).

4.3.1.2.1. The Procedure for Quantifying the Quantitative Targets d1, d2, d3, d4, and d5

In order to quantify the quantitative targets, we adopt the usual section function approach (Dai 1994). Usually, a linear section function approach is popularly adopted. However, because of inherent nonlinearities in the preferences with respect to the different values of each of the target d1, d2, d3, d4, and d5, we preferred to adopt the following section index function

$$f(x) = \log_a(x) + b, \qquad (4.8)$$

where x is the target criterion value, and $f(x)$ $(\in [1, 10])$ is the corresponding evaluation score. (The experts agreed that the form of this function satisfactorily reflects the relative scores ascribed to the different target values.) The function $f(x)$ is derived for each target to be applied over ranges of values by determining the parameters a and b using the scores ascribed by the experts to the end-points of the ranges. These ranges are determined based on sectioning the natural domain of x into intervals based on the experts' opinion such that the trend in preferences can be captured by one set of parameters in (4.8) within each interval, but its structure changes significantly from one interval to another so that a different set of parameter is required in (4.8) to describe the preferences for different intervals. This is done below for each of the targets d1, d2, d3, d4, and d5 under the umbrella B1 in Figure 2. By applying the resulting function $f(x)$ to the actual ascribed target value, we can then compute the evaluation matrix $\overline{B}_1$ in Equation (4.1).

(i) **Net present value rate (d1):** Using $(x, f(x)) \equiv$(0.05, 2), (20, 10), and (50, 2), we compute: (a, b) = (2.11474, 6.00) for d1 $\in$ [0.05, 20], and (a, b) = (0.89117, 36.1552) for d1 $\in$ [20, 50].

(ii) **Internal rate of return (d2):** Using $(x, f(x)) \equiv$(20%, 3), (200%, 10), and (300%, 4), we compute: (a, b) = (1.389495, -6.1072) for d2 $\in$ [20%, 200%], and (a, b) = (0.934655, -3.63739) for d2 $\in$ [200%, 300%].

(iii) **Investment return rate (d3):** In this Thesis, we use the same method to compute d3 and e2 because of their common characteristics (see Section 2.3.2.2 below).

(iv) **Investment recovery period (d4):** Using $(x, f(x)) \equiv$(2, 10) and (6, 3), we compute: (a, b) = (0.85475, 14.4165) for d4 $\in$ [2, 6].

(v) **Total investment amount (d5):** Using $(x, f(x)) \equiv$(0.5, 2), (2, 5), (5, 10), (50, 4), and (200, 2), we compute: (a, b) = (1.5847, 3.5) for d5 $\in$ [0.5, 2], (a, b) = (1.2011, 1.2176) for d5 $\in$ [2, 5], (a, b) = (0.68129, 14.19382) for d5 $\in$ [5, 50], and (a, b) = (0.5, 9.64385) for d5 $\in$ [50, 200].

4.1.3.2.2. Quantifying the Industry Economic Targets e1 and e2

From the discussion in Section 2.1.2, we know that a greater industry investment density would entail a lesser attraction for foreign capital based on needs, and similarly, the greater the industrial investment profit rate of the project, the higher the potential for the project to attract investments. The datum of the Yanbian Statistics Yearbook (1995) provides information on the asset amounts and profit rates for the different industries involved with the various projects. Using the sectioning method with linear functions (which the experts ascertained provides a better fit in this case), we derive the following scoring valuation functions $f(x)$ ($\in$[1, 10]) for the target values x for e1 and e2.

(i) **Industry investment density (e1):**

$$f(x) = \begin{cases} 10 & if \quad x \le 100 \\ 12 - 0.02x & if \quad 100 < x \le 300 \\ 9 - 0.01x & if \quad 300 < x \le 800 \end{cases}$$

where x is the industry investment density.

(ii) **Industrial investment profit rate of the project (e2):**

$$f(x)=\begin{cases} 2 & if \quad x \le 10 \\ 5.5+0.05x & if \quad 10 < x \le 50 \\ 7+0.02x & if \quad 50 < x \le 100 \\ 10 & if \quad x > 100 \end{cases}$$

where x is the industrial investment profit rate. Applying these functions to the actual target values yields the evaluation matrix $\overline{B}_2$ in Equation (4.1).

4.1.3.2.3. The Procedure for Quantifying Qualitative Targets

The qualitative targets were ascribed evaluation scores in the range [1, 10] as follows by the experts, based on the investment environment of China's Tumen River Area (Li et al. 1995) and the goal market situation of products. These scores then provide direct entries for the evaluation matrices $\overline{C}_1$, $\overline{C}_2$, and $\overline{C}_3$ in Equation (4.1).

(i) **Government funding class (f1):**

Governments	Hunchun	Yanbian prefecture	Yanji,Tumen	others
Scores	10	8	8	7

(ii) **Construction location (f2):** the following basic scores were ascribed to the projects located within the listed cities. The scores for the projects in the suburbs and villages in the neighborhood of each of these cities should be relatively reduced. Based on querying the experts, this reduction in grade was taken as a unit value.

Construction locations	Border economic cooperation zone	Hunchun	Yanji,Tumen	Longjing, Dunhua	Helong, Antu	Wanqing
Scores	10	9	9	8	8	6

(iii) **Condition for supplying raw material (g1)**:

Raw material conditions	Local processing	Northeast China	Yanbian	Other places in China	Import
Scores	10	8	6	5	5

(iv) **Dominant degree of the product (h1):**

Product conditions	Import replacement	No production in China	No production in Northeast China	No production in Yanbian	Increase in local production to meet demands
Scores	10	8	8	6	6

(v) **Market demand of the product (h2):**

Objective market	National	Northeast China	Yanbian	Export
Scores	10	8	6	8

Therefore, we can computer the scores for the third level targets for all the projects (see

Appendix A)

4.1.4. Implementation Submodel

Recall that the overall process of Figure 4.1 requires the initial set of projects to be evaluated, and the project having the highest v_i value in Equation (4.6) to be recommended for implementation first. Alternatively, a suitable related group of highly ranked projects could be simultaneously implemented. The simulation submodel serves mainly to assess the effect of this project adoption scheme on the local economy in order to update the fourth-level target values for subsequent assessments. The iterative process then re-evaluates the remaining projects based on this updated information, and the procedure is repeated until either all the projects have been implemented or none of the remaining projects are recommended for implementation. The updating of the target values at any alternation in this iterative process is effected via certain *system state variables* and via two other types of variables in the system: the *feedback state variables* and the *accumulating output variables*. The former refers to the investment profit rate and the investment density, which are periodically recomputed or updated during the course of the process. The latter types of variables are sequentially incremented based on the results obtained at each iteration, with the final value reported as an output for conducting further analyses. These variables are instrumental to the study because they reflect the effect on the local economy, and are discussed in turn in Sections 4.1.4.1 and 4.1.4.2 below. Some further comments on this process are provided in Section 4.1.4.3.

4.1.4.1. Feedback state variables

The feedback state variables are mainly used to analyze the state of the economy and to track the updating of the various economic targets pertaining to the affected industrial sector after a series of investments have occurred in the China's Tumen River Area. This involves monitoring the following variables to assess the changing economic conditions in each industry and in the entire industrial sector: assets, labor, tax, production output, and export.

4.1.4.2. Accumulating Output Variables

This type of variables is mainly used to study the accumulating effect on the efficiency of the industrial sector and on each of its components in regard to several economic activities such as production, sales, and export. By inspecting the changing trends in the production rate, the output rate, and the degree of dependence on exports, we can further characterize the dominant industries in the economy and the status of their developmental stages. For this purpose, we need to identify the changes in the following variables pertaining to each industry as well as to the entire industrial sector: labor productivity, capital output rate, capital profit rate, and the degree of export dependence.

4.1.4.3. Overall Simulation Procedure

In the simulation submodel, we assume that: (1) all projects are viable for implementation, (2) the funds and credits required to implement the projects can be guaranteed, and (3) when simulating, the effects of the various projects on assets is proportional to the respective investments in the projects. The latter assumption makes this a deterministic simulation process. If adequate data is available regarding probability distributions on the effects of various investments on different assets or economic indices, we can implement a stochastic simulation process instead (see Law and Kelton (1991), and Banks et al. (1996) for a general discussion on the subject of simulation).

The steps in the simulation process are as follows.

1. Evaluate the current set of projects under active consideration to compute their comprehensive evaluation grade, v_i, as given by Equation (4.6). Select the project ranked first by this process, and suppose that this project is implemented.
2. Identify the industry in which the selected project is located.
3. Operate on the system state, feedback state, and accumulating output variables related to this identified industry.
4. Operate on the system state, feedback state, and accumulating output variables related to the entire industrial sector.
5. Update the project and target information in the original database and repeat this stepwise process, until either all the projects have been considered or until none of the remaining projects are recommended for implementation. The latter decision can be based on the projected rate of return on the investment in the particular project, in comparison with the corresponding industry's minimal capital rate of return.

Steps 3 and 4 in the above process involve the following types of updates. Suppose that at some iteration k, we have selected the kth ranked project and that this project pertains to some ith industry. Then we perform the following updates.

$$A_i(k) = A_i(k-1) + \alpha \cdot I_k$$
$$L_i(k) = L_i(k-1) + L_k$$
$$R_i(k) = R_i(k-1) + R_k$$
$$O_i(k) = O_i(k-1) + O_k$$
$$E_i(k) = E_i(k-1) + E_k$$
$$RP_i(k) = \frac{O_i(k)}{L_i(k)}$$
$$RO_i(k) = \frac{O_i(k)}{A_i(k)}$$
$$RR_i(k) = \frac{R_i(k)}{A_i(k)}$$
$$RD_i(k) = \frac{E_i(k)}{O_i(k)}$$

where,

$A_i(k)$ is the asset amount for the ith industry at the kth iteration;

α is the coefficient of transformation of investments into assets;
I_k is the investment amount of the selected k th ranked project;
$L_i(k)$ is the labor force for the i th industry at the k th iteration;
L_k is the labor force of the selected k th ranked project;
$R_i(k)$ is the profit for the i th industry at the k th iteration;
R_k is the profit of the selected k th ranked project;
$O_i(k)$ is the output for the i th industry at the k th iteration;
O_k is the output of the selected k th ranked project;
$E_i(k)$ is the export for the i th industry at the k th iteration;
E_k is the export of the selected k th ranked project;
$RP_i(k)$ is the labor productivity for the i th industry at the k th iteration;
$RO_i(k)$ is the capital output for the i th industry at the k th iteration;
$RR_i(k)$ is the rate of capital return for the i th industry at the k th iteration;
$RD_i(k)$ is the export dependence degree for the i th industry at the k th iteration.

These updated economic indices are then used to evaluate the targets at the fourth level in Figure 4.2 for the remaining projects in the subsequent iteration.

4.2. Results for the Evaluation Analysis

Based on the net evaluation values v_i computed and updated iteratively via Equation (4.6), as in the foregoing section using the overall assessment and simulated implementation process of Figure 4.1, we obtained a rank ordering of all the 103 projects(see Appendix B). During the procedure, no project was eliminated because each project's investment return rate was no lesser than the corresponding industry's minimal capital rate of return. The project rankings obtained via this overall process are given below, where the projects have been further classified into five groups based on the consultation advice of the aforementioned experts. (Here, the evaluation indices v_i correspond to the particular values at the respective iterations where project i is selected as the next best investment alternative.)

(1) The most competitive projects (Numbers 1 - 20)

Rank Order	1	2	3	4	5	6	7	8	9	10
Project Number	36	110	7	78	112	17	85	102	90	27
Evaluation Index v_i	7.742	7.739	7.585	7.577	7.563	7.535	7.522	7.514	7.482	7.462
Location	Hunchun	Hunchun	Hunchun	Dunhua	Antu	Tumen	Hunchun	Yanji	Antu	Hunchun
Total investment amount (Million US $)	4.90	8.74	5.53	5.92	5.43	5.41	3.26	3.67	5.87	8.95

Rank Order	11	12	13	14	15	16	17	18	19	20
Project Number	81	92	29	12	79	8	30	83	116	25
Evaluation Index v_i	7.413	7.404	7.394	7.388	7.347	7.346	7.298	7.296	7.185	7.151
Location	Longjing	Hunchun	Dunhua	Yanji	Yanji	Longjing	Dunhua	Longjing	Dunhua	Longjing
Total investment amount (Million US $)	5.10	3.46	3.24	1.89	3.57	2.50	12.1	6.00	28.3	6.57

These projects are the most competitive in attracting foreign investments. The various projects in this group are distributed across all the principal industries except for the chemical industry, the oil industry, and the medical industry.

(2) Relatively competitive projects (Numbers 21 - 50)

Rank Order	21	22	23	24	25	26	27	28	29	30
Project Number	89	19	109	108	14	96	22	100	4	35
Evaluation Index v_i	7.141	7.139	7.136	7.133	7.125	7.112	7.073	7.069	7.050	7.050
Location	Yanji	Longjing	Hunchun	Yanji	Yanji	Hunchun	Dunhua	Yanji	Yanji	Hunchun
Total investment amount (Million US $)	3.13	3.87	16.7	19.6	2.43	2.75	6.72	1.86	3.00	1.72

Rank Order	31	32	33	34	35	36	37	38	39	40
Project Number	6	94	84	32	106	15	23	105	11	77
Evaluation Index v_i	7.047	7.046	7.035	7.027	7.026	7.020	7.002	6.989	6.972	6.957
Location	Hunchun	Yanji	Antu	Helong	Hunchun	Wangqing	Yanji	Longjing	Antu	Longjing
Total investment amount (Million US $)	1.29	30.24	4.22	13.7	0.93	1.31	3.00	1.76	1.26	9.44

Rank Order	41	42	43	44	45	46	47	48	49	50
Project Number	103	34	95	114	101	111	31	18	91	104
Evaluation Index v_i	6.956	6.948	6.936	6.932	6.932	6.929	6.891	6.886	6.882	6.854
Location	Dunhua	Antu	Hunchun	Yanji	Tumen	Hunchun	Hunchun	Longjing	Helong	Longjing
Total investment amount (Million US $)	1.44	1.67	1.81	31.6	8.10	1.17	1.14	12.4	10.6	4.52

This group of projects exhibited a greater difference in the internal economic target values and the target values concerning the potential for future profit realizations as compared with the first group of projects. However, there was only a little difference in the external economic target values for these two groups of projects.

(3) Projects having an average competitiveness (Numbers 51 - 70)

Rank Order	51	52	53	54	55	56	57	58	59	60
Project Number	24	82	97	10	33	20	61	9	87	43
Evaluation Index v_i	6.850	6.825	6.818	6.771	6.754	6.702	6.692	6.677	6.667	6.655
Location	Longjing	Longjing	Wangqing	Yanji	Helong	Longjing	Yanji	Longjing	Helong	Wangqing
Total investment amount (Million US $)	1.94	25.0	3.77	20.3	7.85	1.81	2.22	0.86	16.2	7.89

Rank Order	61	62	63	64	65	66	67	68	69	70
Project Number	69	26	46	99	75	1	54	3	80	62
Evaluation Index v_i	6.627	6.609	6.600	6.568	6.544	6.536	6.507	6.491	6.488	6.446
Location	Dunhua	Hunchun	Dunhua	Dunhua	Yanji	Hunchun	Yanji	Yanji	Yanji	Tumen
Total investment amount (Million US $)	5.47	35.1	8.87	1.60	2.96	2.20	2.65	0.52	94.9	3.90

This group of projects is mainly distributed across the chemical industry, the oil industry, and the medical industry, and offer a relatively stable form of investment. However, because the external economic evaluation indices for the industries that contain this group of projects are relatively lower, this group offers only an average level of competitiveness.

(4) Projects having below-average competitiveness (Numbers 71 - 90)

Rank Order	71	72	73	74	75	76	77	78	79	80
Project Number	51	28	66	2	64	21	50	41	65	28
Evaluation Index V_i	6.442	6.381	6.370	6.323	6.315	6.287	6.282	6.235	6.187	6.176
Location	Hunchun	Tumen	Dunhua	Helong	Hunchun	Longjing	Hunchun	Hunchun	Hunchun	Dunhua
Total investment amount (Million US $)	10.6	135.6	11.3	1.05	1.80	1.58	1.19	0.93	3.41	24.7

Rank Order	81	82	83	84	85	86	87	88	89	90
Project Number	70	68	59	86	48	56	71	73	57	47
Evaluation Index V_i	6.173	6.161	6.153	6.117	6.090	6.065	6.034	6.027	5.981	5.954
Location	Yanji	Yanji	Tumen	Yanji	Helong	Tumen	Longjing	Yanji	Tumen	Tumen
Total investment amount (Million US $)	2.65	1.63	17.8	16.8	12.7	0.96	4.46	2.33	1.10	21.9

There are various internal or external shortcomings for the projects in this group, which are mainly distributed across the chemical industry and the oil industry. If these shortcomings can be overcome, these projects might become attractive for foreign investments. It is worthy to note that the differences in the targets values between this group of projects and the third group are very significant.

(5) Noncompetitive projects (Number 91 - 103)

Rank Order	91	92	93	94	95	96	97	98	99	100
Project Number	76	67	74	40	58	53	63	49	44	55
Evaluation Index V_i	5.868	5.844	5.808	5.776	5.690	5.572	5.563	5.498	5.493	5.450
Location	Yanji	Dunhua	Yanji	Tumen	Hunchun	Hunchun	Hunchun	Tumen	Hunchun	Yanji
Total investment amount (Million US $)	1.00	0.76	3.91	0.82	18.7	1.85	13.7	6.76	0.71	1.63

Rank Order	101	102	103
Project Number	42	45	60
Evaluation Index V_i	5.420	5.186	4.977
Location	Longjing	Tumen	Tumen
Total investment amount (Million US $)	8.24	18.20	91.2

This group of projects resides within the chemical industry, the oil industry, and the heavy chemical industry. Because these projects have relatively lower values of the financial targets, and because the investment density in these industries is quite high, it is very difficult for foreign investors to enter into this sector of the economy. Hence, the designated categorization of this group of projects.

Based on the foregoing analysis, we can assess the overall economic impact of investments in the first four groups of projects. (We assume that the group of noncompetitive projects does not attract any investments under the present conditions.) Furthermore, suppose for the sake of illustration that each of the remaining four groups of projects are implemented in stages, where each stage corresponds to each group in the stated order above. Table 4.1 provides information regarding certain key economic indices pertaining to each individual group of projects. By (deterministically) simulating the changing economic conditions in China's Tumen River Area based on these investments as they occur stage by stage (following a procedure similar to that in Section 2.4.3 above), we obtain the results presented in Table 4.2. Here, the profit rate is defined as [profit / investment density], the labor productivity is defined as [output / labor], the capital output rate is defined as [output / investment density], and the export dependence degree is defined as [grand total export / output].

Two principal motivations for attracting foreign investments are to enhance exports and industrial outputs. Tables 4.3 and 4.4 provide information regarding the simulated effects on exports and outputs in individual industries in China's Tumen River Area based on investments in the above four groups of projects. This information provides useful insights for planners on future economic trends, and the ensuing anticipated needs in the area for the necessary supporting infrastructure. In Tables 3 and 4, based on UNIDO's industrial division definition, Industry 3.1 is the Food, Drink, and Tobacco Manufacturing industry, Industry 3.2 is the Textile, Clothing, and Leather industry, Industry 3.3 is the Timber and Timber Products (including wooden furniture) industry, Industry 3.4 is the Paper, Printing, and Publishing industry, Industry 3.5 is the Oil, Chemical, Coking, Rubber, and Plastic Products industry, Industry 3.6 is the Nonmetal Minerals industry, and Industry 3.8 is the Mechanical and Electric Products industry which is further detailed into the Metal Products Manufacturing industry (Industry 3.8.1), the Mechanical Installations Manufacturing industry (Industry 3.8.2), and the Electrical Installations and Cells Manufacturing industry (Industry 3.8.3). (There is no project in Industry 3.7, which is the Basic Metal industry.)

Table 4.1. Economic Indices for Each Individual Group of Projects.

Projects	Total investment (Million $)	Profit (Million $)	Capital stock (Million $)	Loan (Million $)	Labor (Persons)	Output (Million $)	Export (Million $)	Export dependence degree
Group 1	130.29	136.18	55.52	74.77	5959	329.17	48.64	0.15
Group 2	203.63	134.52	112.76	90.87	11360	372.50	73.78	0.20
Group 3	246.25	224.45	54.97	191.28	4448	270.67	20.57	0.08
Group 4	274.79	115.24	105.45	169.34	3864	262.25	41.57	0.16

Table 4.2. The Economic Impact in China's Tumen River Area after Simulating Investments.

Projects	Investment density (Million $)	Profit (Million $)	Profit rate (%)	Labor (Persons)	Output (Million $)	Grand total export (Million $)	Labor productivity ($/person)	Capital output rate (%)	Export dependence degree (%)
Initial values	1105.185	88.301	7.99	183920	735.5	45	3999	66.550	6.1
Group 1	1207.175	224.481	18.60	189879	1064.670	93.460	5607	86.175	8.8
Group 2	1410.805	359.001	25.45	201239	1437.170	167.240	7141	101.869	11.6
Group 3	1657.055	583.451	35.21	205687	1707.840	187.810	8303	103.065	11.0
Group 4	1931.845	698.691	36.17	209551	1970.090	229.380	9401	101.980	11.6

Table 4.3. Simulated Exports (Million US $).

	Industry / Target	3.1	3.2	3.3	3.4	3.5	3.6	3.8.1	3.8.2	3.8.3
Initial	Exports	19.38	5.06	3.38	4.35	8.52	3.43	0.3	0	0
	Proportion of Exports	44.2%	11.3%	7.53%	9.69%	19.0%	7.64%	0.68%	0.00%	0.00%
After Simulation	Exports	37.17	37	25.46	36.95	20.83	40.09	2.21	7.89	19.49
	Proportion of Exports	16.4%	16.3%	11.2%	16.1%	9.19%	17.7%	0.97%	3.48%	8.60%

Table 4.4. Simulated Industrial Outputs (Million US $).

	Industry / Target	3.1	3.2	3.3	3.4	3.5	3.6	3.8.1	3.8.2	3.8.3
Initial	Outputs	146.77	62.48	56.26	72.54	169.01	58.07	16.85	32.11	9.78
	Proportion of Outputs	23.5%	10.0%	9.02%	11.6%	27.1%	9.31%	2.70%	5.15%	1.56%
After Simulation	Outputs	192.7	173.44	141.48	181.08	360.97	324.5	85.79	64.27	98.82
	Proportion of Outputs	11.8%	10.6%	8.72%	11.1%	22.2%	20.0%	5.29%	3.96%	6.07%

Chapter 5

Summary and Conclusions

5.1 Regional Technological Cooperation Mechanisms

A necessary condition for a regional technological cooperation to occur is that every participant must be motivated by some incentive to change the status of technological development among the participants to complement each other's needs and objectives. A sufficient condition for inducing regional technological cooperation is that the participants in the coalition that emerges are able to coordinate payoff distributions, by using effective consultations, in order to reach binding agreements and mechanisms for conducting the technology transfer and regulating the payoff distributions. Moreover, the net effect of this cooperation should be that each participant enjoys an overall benefit that exceeds the expected reservation utility in isolation, prior to taking part in the cooperative effort.

We have described in this thesis a cooperative game among players participating in a technology transfer via the definition of a suitable characteristic function which reflects net benefits under various scenarios of cooperative coalitions. We have shown that the game thus defined is convex, and hence, payoff distributions that are determined via the Shapley value allocations are in the core, and therefore, prescribe a stable and rational compensation mechanism. Moreover, this Shapley value distribution scheme has been computed via a closed-form formula that affords useful economic interpretations.

In practice, while implementing a regional technological cooperation plan among countries that widely differ in levels of technology, the countries which have a relatively lower technological ability and level might generally impose high tariffs to interrelated products in order to protect their own industries, and might also have a lower ability and level of competitiveness when implementing the technology transfer. Therefore, the above-mentioned payoff compensation mechanism is necessary in order to guarantee that the final payoff of each participant is rational. The property which ensures that such a payoff compensation mechanism provides a net utility gain for each participant, is the essence of inducing a regional technological cooperation.

5.2 Foreign Direct Investment Projects in China's Tumen River Area

5.2.1. The Current State of Foreign Investment in China's Tumen River Area

China's Tumen River Area comprises the Yanbian Korean Autonomous Prefecture in China's Northeastern Jilin Province, and includes its capital, Yanji City, along with Hunchun City, Tumen City, Dunhua City, Longjing City, Antu County, and Wanqing County. This region has an area of 42,700 sq km, and had a population of 2.2 million by the end of 1999, of which 40% were Korean Chinese and 57% is Han Chinese. In Yanbian, 3.037% get college education, which is 2.1 times the average over all of China. This region is bounded by China (proper) and Russia in the North over a border line of 232.7 km, and by China and Democratic people's Republic of Korea in the South over a border line of 552.5 km. The nearest region of Yanbian is only 4 km away from the Sea of Japan.

In Yanbian, the forest territory is 3.7 million hectares. 78.2% of Yanbian is covered with forests and the total wood reserves are 300 million cubic meters. There are rich mineral resources and rich local specialties in Yanbian. There are about 487 rivers in Yanbian and the total of the power resources is about 1.4 million kw, of which 47,000 kw are being used. The Yanbian economy generated a GDP of $US 1.52 billion in 1999. The growth in GDP since 1995 has maintained a 5-8% per annum rate. The main economic sectors in Yanbian are industry and construction, and the service sector, each with 42% of GDP in 1999. This level is double that of twenty years ago. In 1999, the total amount of international trade in Yanbian was $US 279 million, of which imports amounted to $US 125 million and exports to $US 154 million.

Foreign investment in China's Tumen River Area did not start in earnest until 1990, some ten years later than in southern and eastern China. By the end of 1999, Yanbian had registered 800 foreign investment enterprises (see Table 5.1 for details of sources of foreign investments), and had attracted $US 500 million ($US 103 million by end of 1994) (see Table 5.2 for details of actually-used foreign investments). These foreign investment enterprises in Yanbian accounted for a total export of $ US 80 million (see Table 5.3). The upsurge in foreign capital inflow in 1995-1999 was also associated with a major transition toward attracting larger scale investments. Prior to 1995, no large-scale investment occurred, but by the end of 1999, Yanbian's ten largest foreign enterprise projects (see Table 5.4), each exceeded $US 5 million in foreign capital.

Table 5.1. Sources of Foreign Investments in 1999.

ROK	Hong Kong	Japan	USA	Taiwan	DPRK	Others
55%	15%	15%	7%	4%	1%	3%

Table 5.2. Actually-Used Foreign Investments ($US Million) in 1999.

1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
0	1	2	5	28	68	78	134	95	44	39

Table 5.3. Exports from the Foreign Investment Enterprises in Yanbian ($US Million) in 1999.

1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
0	0.5	1	5	7.5	19	39	46	65	59	80

Table 5.4. Top Ten Foreign Investment Projects in Yanbian over 1990-1999 ($US Million).

Order	Source of Foreign Investment	Name of Enterprise	Form of Cooperation	Business Area	Actual Investment
1	ROK	Jilin Shangbanger Textile Ltd	Wholly-Owned	Textile Fabrics	60.00
2	HK	Jilin Fudun Wood Industry Ltd	Joint Venture	Medium-density Fibre-board	18.00
3	Malaysia Japan	Anli International (Yanbian) Timber	Wholly-Owned	Plywood	15.20
4	ROK	Dayan Centre Ltd (Daewoo)	Joint Venture	Daewoo Hotel Service	13.80
5	Malaysia	Jilin Lalu Antu Liangjiang Hydropower Ltd	Joint Venture	Hydroelectric Power	12.65
6	Japan	Yanji City Guiwan Foodstuffs	Joint Venture	Soy Sauce	8.69
7	HK	Yanbian Lijian Wood Products	Wholly-Owned	Wood Products	7.60
8	USA	Yanji City Water Co	Joint Venture	Water Supply	6.49
9	HK	Dunhua Chaohua Coop. Agriculture/Forestry Products Dev. Co	Joint Venture	Wood Products	6.40
10	ROK	Jilin Hyundai Steel Pile Processing Ltd	Wholly-Owned	Welded Steel Pipe	6.00

5.2.2. Probability Analysis

In the foregoing sections, we obtained a rank ordering of all the 103 projects and classified these projects into five groups. From this discussion, we can use at least two methods to further analyze this topic probabilistically as follows.

First, we can use the classical probability method to discuss the topic. The highest score and the lowest score of the targets in the third layer are respectively 10 and 0. Because the value of the evaluation index v_i for project i (see Appendix B) divided by 10 is between 1 and 0, and this directly reflects the possibility of this project attracting investment, we can roughly consider the probability on the event for Project i to form investment as $p_i = \frac{v_i}{10}$ for $i = 1, \cdots, 103$. Therefore, we can obtain a new Table 4.1 by calculating the expected value of each term in Table 4.1. For example, the total expected investment for Group 1 can be obtained by

$$\text{Total expected investment for Group 1} = \sum_{i=1}^{20}[\frac{v_i}{10} \times (\text{Total investment amount of Project } i)]$$
$$= \$96.8 \text{ (million).}$$

In this meaner, we can derive the new Tables 4.2, 4.3, and 4.4.

Second, we can use the experiential probability method to discuss this topic. For example, we have known that 95%, 90%, 85%, 35%, and 7% of the projects from each of the groups 1-5 have formed investment from the discussion in Section 5.3.3. If we extrapolate that the experiential probability that the projects in each of these groups 1-5 will form an investment is 95%, 90%, 85%, 35%, and 7%, respectively, we can also obtain a new Table 4.1 by calculating the expected value of each entry in Table 4.1. For example, the total expected investment for Group 1 can be obtained as

$$\text{Total expected investment for Group 1} = 0.95 \text{ (Total investment in Group 1)}$$
$$= \$123.78 \text{ (million).}$$

Likewise, this can be used to derive the new Tables 4.2, 4.3, and 4.4.

5.2.3. Conclusion

In this thesis, we have provided a general modeling framework for analyzing projects from the viewpoint of attracting direct foreign investments, and have illustrated this technique on a set of projects proposed for developing China's Tumen River Area. For this purpose, we have described a target system that identifies various key quantitative and qualitative economic factors that influence the selectability of each project. Using expert opinion in concert with the Analytic Hierarchy Process, we have shown how these target system indices can be translated to derive compatible evaluation scores for the various projects. Next, we developed a sequential process in which the highest ranked project is implemented at each step, with the influencing industrial economic factors being updated to recompute the target values and the evaluation scores for the remaining projects. By repeating this step, we derived a rank-ordered list of the different proposed projects. These projects were then grouped into five sets based on their relative competitiveness for attracting foreign investments. Furthermore, by assuming that projects within each of the first four groups which are at least minimally competitive attract investments over stages, where each stage implements an additional group of projects in the derived order, we provided an assessment of this investment scheme on the overall economic indices pertaining to the area. In practice, as of June 2000, some 80 projects in the *" '95 China's Tumen River Area International Investment and Business Forum"* had formed investments. (These include 31, 18, 11, 6, 6, 3, 2, and 3 projects in the cities/counties of Yanji, Hunchun, Dunhua, Longjing, Helong, Wangqing, Tumen, and Antu, respectively). The actual mix of these 80 projects includes 71 projects from the set of 103 projects considered in this paper. Of these 71 projects, 19, 27, 17, 7, and 1 were identified to belong to the groups 1-5, respectively. These respectively constitute 95%, 90%, 85%, 35%, and 7% of the projects from each of the groups 1-5. Hence, the selected projects closely match the top projects ranked by our methodology in Section 4.2. The detailed distribution of these projects that have attracted investment is given in Table 5.5.

Table 5.5. Distribution of Projects Forming Investment (by June, 2000).

	subtotal	Yanji	Hunchun	Dunhua	Longjing	Helong	Wangqing	Tumen	Antu
# of projects from Group 1 (out of 20)	19	3	6	4	3	0	0	1	2
# of projects from Group 2 (out of 30)	27	10 (+2)*	7	2	3 (-2)*	2	1	1	1
# of projects from Group 3 (out of 20)	17	8 (+2)*	2	2	0 (-2)*	2	2	1	0
# of projects from Group 4 (out of 20)	7	3	2	1	0	1	0	0	0
# of projects from Group 5 (out of 13)	1	1	0	0	0	0	0	0	0
# of projects from the total evaluated 103 projects	71	25	17	9	6	5	3	2	3
# of projects from the total 116 projects	80	31	18	11	6	6	3	2	3

* ---- These numbers include the two projects that were transferred to Yanji from (nearby) Longjing within Groups 2 and 3 for economic reasons.

From the results of this analysis, we know that the entrance of foreign investments will exert a tremendous influence on the economic development in this area. Concomitant with this development, various problems, needs, and issues arise with respect to the infrastructure, the socio-economy, and the industrial developmental process. Our analysis provides insights into the projected growth of the economy with respect to various economic factors (see Tables 4.1 – 4.4), and this growth will have implied consequences that need to be assessed within the ongoing planning process.

As far as the infrastructure is concerned, China will need to resume the right to enter the Sea of Japan along the Tumen River to enhance investors' faith, and in general, to enhance its transportation efficiency and performance. Moreover, the water distribution system and the electricity generation capacity will need to be expanded. There exist sufficient water and hydroelectric resources in this area to accommodate this need, but a key problem that will need to be addressed concerns waste disposal and water contamination.

As far as the socio-economic factors are concerned, the demands for loans are anticipated to be very high (about $526 million from Table 4.1), so that there would need to be sufficient funds for supporting these investment plans as well as the necessary accompanying infrastructure. This would call for a coordinated effort between the local governments, the finance divisions, and international organizations. Also, over the four groups of projects, although the assets and the outputs are anticipated to respectively double and triple, the employment opportunities are projected to increase only by 13% (see Table 4.2). Moreover, the required type of labor will need to have higher levels of productivity and skill. The local governments will therefore need to support various workers’ training and professional educational programs.

Finally, as far as the industrial sector is concerned, each industry will need to consider various problems and issues in their respective future development. These include taking vigorous actions to open up international markets, garnering experience in operating within an international arena, enhancing the grade of products, and improving production technology. With proper and careful planning, China’s Tumen River Area will be poised for economic prosperity over the twenty-first century.

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Appendix A

Table of Scores for the Third Level Targets of Projects

Number	Code	d1	d2	d3	d4	d5	e1	e2	f1	f2	g1	h1	h2
1	31	5.894	5.252	4.737	5.247	5.514	180.189	0.420	8.70	9.00	9.00	6.00	7.00
2	31	9.635	9.082	7.162	8.504	3.614	181.367	0.430	6.20	6.50	7.60	5.00	5.00
3	31	7.324	7.010	6.884	6.961	2.085	180.579	0.420	8.70	8.50	8.50	7.20	7.50
4	31	8.224	6.983	4.947	9.893	7.207	160.703	0.370	8.70	8.50	8.50	7.20	7.50
6	31	8.625	8.551	6.079	7.746	4.056	161.671	0.370	9.00	9.00	8.80	8.10	8.10
7	31	7.054	6.582	7.094	5.361	9.738	155.160	0.270	9.90	9.90	7.80	8.30	8.50
8	31	9.608	8.528	5.936	9.565	6.212	158.453	0.340	8.00	6.50	8.50	9.20	9.50
9	31	9.185	4.959	9.430	8.015	3.197	178.539	0.420	7.80	6.50	8.10	7.90	7.50
10	31	6.798	6.333	4.200	7.072	6.340	177.894	0.410	8.30	8.00	8.80	7.00	7.50
11	31	7.509	7.108	6.948	3.077	3.992	162.616	0.370	6.00	6.50	9.80	8.50	8.50
12	31	9.813	5.334	9.716	2.390	4.878	156.578	0.330	9.10	8.50	9.20	8.30	8.10
14	32	9.892	2.767	9.510	7.104	6.062	93.040	0.120	8.60	9.00	7.80	8.00	8.10
15	32	9.934	6.032	9.556	6.203	4.092	99.063	0.180	5.80	6.50	8.30	8.50	8.50
17	32	9.078	8.276	5.864	3.272	9.795	88.314	0.060	9.30	8.50	7.80	7.10	8.80
18	32	6.338	5.537	4.815	2.067	7.629	110.628	0.190	8.00	6.50	8.00	7.80	8.80
19	32	7.170	5.145	5.735	4.296	8.603	91.217	0.070	8.00	6.50	8.30	8.00	8.80
20	32	7.308	6.164	5.741	3.999	4.784	111.986	0.190	8.00	6.50	8.20	7.80	8.80
21	32	6.598	6.016	4.529	5.176	4.490	113.171	0.190	8.00	6.50	7.50	7.50	7.00
22	32	6.060	5.303	4.976	5.785	9.230	98.080	0.150	8.00	6.50	8.20	8.80	8.00
23	32	6.488	5.634	4.910	4.208	7.207	101.313	0.180	9.20	8.00	8.50	7.80	8.50
24	33	6.760	6.486	6.923	6.765	4.932	135.009	0.240	8.00	8.00	9.50	7.00	8.50
25	33	7.416	6.776	4.324	3.132	9.288	121.171	0.190	8.00	6.50	8.80	7.90	8.10
26	33	6.718	6.033	4.324	5.508	4.922	167.222	0.300	9.00	9.90	8.80	7.90	8.10
27	33	6.992	6.414	7.260	4.812	8.483	104.760	0.080	9.00	9.90	8.80	8.30	7.90
28	33	4.895	3.718	2.516	4.785	5.831	185.792	0.320	8.00	6.50	9.30	7.90	8.10
29	33	7.624	7.702	6.321	8.749	7.632	107.109	0.110	8.00	6.50	9.30	8.80	8.80
30	33	7.167	6.642	6.823	7.820	7.704	116.243	0.180	8.00	6.50	9.30	8.50	8.10
31	33	8.463	8.782	5.536	8.062	3.784	133.554	0.230	9.90	9.90	8.80	8.50	8.00
32	33	6.588	5.837	4.637	4.418	7.374	131.446	0.210	6.50	9.30	9.50	9.20	8.10
33	33	1.055	9.461	3.015	4.605	8.826	140.897	0.250	6.50	6.50	9.00	8.90	8.10
34	33	9.460	9.500	6.020	6.919	4.605	132.699	0.210	6.20	6.50	8.90	9.20	8.30
35	34	7.349	7.019	7.039	4.860	4.668	116.722	0.050	9.00	9.90	8.30	8.50	9.50
36	34	8.974	9.170	5.997	6.349	9.885	115.432	0.050	9.90	9.90	7.50	9.50	9.50
38	34	6.642	5.728	5.728	2.119	2.561	218.422	0.140.	9.00	7.90	7.90	8.00	9.20
40	35	9.235	9.667	9.667	6.257	3.071	362.822	0.380	9.00	8.20	7.90	7.90	8.20
41	35	8.961	9.186	9.186	7.372	3.343	306.179	0.250	9.90	9.90	8.50	9.50	9.50
42	35	3.835	3.367	3.367	3.717	8.698	401.592	0.380	8.30	8.00	8.00	7.50	8.50
43	35	8.614	7.799	7.799	7.988	8.783	268.811	0.140	5.30	6.50	7.90	7.90	8.80
44	35	7.397	7.730	7.730	7.955	2.744	394.189	0.380	9.90	9.90	7.50	8.10	8.00
45	35	2.784	3.025	3.025	2.964	6.633	415.242	0.380	9.00	8.00	8.00	8.50	8.00
46	35	7.961	8.137	8.137	9.622	8.506	279.567	0.190	8.30	6.50	8.50	8.80	8.80
47	35	7.259	7.098	7.098	7.809	6.050	357.954	0.370	9.00	8.00	8.00	8.10	8.00
48	35	7.492	7.499	7.499	7.416	7.555	334.891	0.320	6.50	6.50	8.00	8.50	8.50
49	35	2.813	3.097	3.097	3.262	9.214	393.656	0.380	9.00	8.00	8.00	8.10	8.20
50	35	7.384	6.818	6.818	8.557	3.867	3.5.481	0.240	9.90	9.90	9.20	9.50	8.90
51	35	7.597	6.761	6.761	5.531	8.020	294.718	0.220	9.90	9.90	8.30	8.80	8.90
53	35	5.253	4.421	4.421	4.746	4.835	378.243	0.380	9.00	8.00	9.20	9.50	8.90
54	35	8.636	8.437	8.437	3.054	6.530	283.775	0.200	9.00	8.00	8.30	8.10	9.50
55	35	5.585	4.792	4.792	5.214	4.557	395.412	0.380	9.00	8.00	8.00	7.80	8.80
56	35	9.425	8.737	8.737	2.994	3.412	335.611	0.330	9.00	8.00	8.00	7.80	8.10
57	35	8.894	9.249	9.249	5.787	3.706	341.529	0.340	9.90	9.90	8.00	7.80	8.50

Number	Code	d1	d2	d3	d4	d5	e1	e2	f1	f2	g1	h1	h2
58	35	5.242	4.435	3.312	4.616	6.561	376.855	0.380	9.00	9.00	9.00	7.80	8.50
59	35	7.422	7.249	6.529	8.326	6.690	325.306	0.300	9.00	8.00	8.00	7.80	8.50
60	345	5.055	4.276	3.346	4.334	3.133	483.642	0.380	9.00	8.00	8.00	7.80	8.50
61	35	9.046	4.637	8.333	5.621	5.557	262.826	0.080	9.00	8.00	9.50	9.50	9.50
62	35	6.900	6.592	6.766	7.078	8.639	586.70	0.210	9.00	8.00	8.00	7.80	8.80
63	35	4.093	3.530	2.093	2.091	7.356	388.58	0.380	9.00	9.90	8.50	7.90	9.50
64	35	9.253	9.998	5.758	7.481	4.772	304.58	0.240	9.00	9.90	8.80	8.00	8.50
65	35	7.082	6.336	4.486	3.230	7.906	308.73	0.250	9.00	9.90	8.50	8.00	8.30
66	35	8.258	6.940	5.285	6.679	7.862	303.23	0.240	8.00	6.50	8.80	8.80	8.50
67	35	9.347	9.923	5.823	8.289	2.906	359.27	0.380	8.00	6.50	8.50	8.50	8.90
68	35	7.643	8.726	8.409	8.254	4.563	311.94	0.260	9.00	8.00	8.00	8.00	8.50
69	35	7.662	7.386	7.258	7.200	9.765	272.91	0.150	8.00	6.50	8.00	8.00	8.00
70	35	8.107	7.722	6.694	6.657	6.530	310.72	0.250	9.00	8.00	7.80	8.00	8.30
71	35	6.718	5.902	4.618	2.788	9.374	338.95	0.330	8.00	6.50	8.00	8.30	8.00
73	35	7.684	8.143	5.828	8.699	5.828	340.70	0.340	9.00	8.00	8.00	8.50	8.50
74	35	4.823	4.071	3.792	4.236	8.648	362.20	0.380	9.00	9.00	8.30	8.30	8.00
75	35	9.095	9.285	6.459	9.930	7.131	281.78	0.200	9.00	8.00	8.30	8.30	8.10
76	35	9.219	6.010	8.691	4.277	3.500	358.70	0.380	8.50	8.00	8.30	8.10	8.00
77	36	6.865	5.347	3.580	7.457	8.344	137.55	0.220	7.60	6.50	9.50	8.50	8.50
78	36	7.808	7.252	6.7.1	2.003	9.559	107.17	0.030	8.00	8.00	8.90	8.90	8.30
79	36	7.366	6.888	6.851	5.359	8.157	120.45	0.120	9.00	8.00	8.80	8.00	8.90
80	36	7.630	7.877	5.594	9.419	3.075	247.67	0.710	9.00	8.00	8.80	8.00	8.90
81	36	7.217	6.594	7.323	6.346	9.994	117.78	0.110	7.50	6.50	8.50	8.30	8.30
82	36	7.284	6.718	6.891	6.955	5.806	164.28	0.310	8.00	6.50	8.50	8.50	8.50
83	36	9.259	5.695	5.559	7.049	9.525	124.95	0.150	8.00	6.50	8.50	8.50	8.50
84	36	6.249	5.276	5.212	4.378	9.000	130.47	0.180	5.80	6.50	8.90	8.80	8.90
85	36	7.837	7.550	6.832	8.181	7.661	1.9.61	0.050	9.00	9.90	8.50	9.30	9.30
86	36	5.988	5.317	4.895	5.542	6.841	260.27	0.710	9.00	8.00	8.10	7.80	8.10
87	36	7.907	6.919	4.559	3.656	6.925	176.49	0.310	5.80	6.50	8.80	8.50	8.50
89	36	7.235	7.172	6.713	7.999	7.439	127.30	0.170	9.00	8.00	8.30	8.30	8.30
90	36	9.249	9.690	5.889	7.641	9.583	114.02	0.090	6.00	6.50	8.50	8.10	8.50
91	36	6.630	5.993	4.366	5.079	8.030	145.53	0.240	6.00	8.00	8.90	8.80	8.80
92	37	7.533	7.035	7.378	8.932	7.986	39.924	0.180	9.90	9.90	8.00	8.00	8.20
94	381	8.119	8.215	6.151	8.975	5.310	54.721	0.730	9.00	8.00	8.30	8.00	8.10
95	381	6.192	5.201	5.531	4.750	4.783	56.079	0.720	9.90	9.90	8.50	9.30	9.00
96	381	6.704	6.047	4.538	7.055	6.732	30.646	0.080	9.90	9.90	8.50	8.90	8.80
97	381	5.439	4.627	3.171	3.245	8.459	58.907	0.700	5.00	6.50	9.30	8.50	8.30
99	381	5.833	5.118	5.203	5.526	4.517	60.107	0.700	8.00	6.50	8.30	8.30	8.50
100	381	8.158	8.247	6.321	9.092	4.843	32.041	0.170	9.00	8.00	8.50	8.30	8.30
101	382	4.963	4.089	3.825	3.251	8.743	66.226	0.200	9.00	8.00	8.30	8.50	8.50
102	382	8.881	8.205	8.805	6.184	8.304	59.071	0.170	8.00	6.50	8.00	8.10	8.30
103	382	9.115	8.995	6.649	8.409	4.289	60.151	0.190	8.00	6.50	8.00	8.20	8.30
104	382	5.648	4.680	3.422	3.150	9.441	69.616	0.210	8.00	6.50	8.00	8.00	8.00
105	383	8.665	8.748	6.080	7.165	4.723	55.640	0.370	8.00	6.50	8.30	8.30	8.50
106	383	8.332	8.286	6.430	6.462	3.343	54.320	0.350	9.90	9.90	8.50	8.30	8.50
108	383	6.962	6.384	7.350	4.500	6.428	53.622	0.350	9.00	8.00	8.50	8.00	8.00
109	383	7.283	6.406	4.602	4.078	6.856	38.854	0.310	9.90	9.90	8.50	8.50	8.50
110	383	9.145	8.665	6.921	6.242	8.546	22.248	0.240	9.90	9.90	8.50	8.70	8.70
111	383	6.765	6.463	7.148	6.852	3.842	56.518	0.380	9.90	9.90	8.50	8.30	8.00
112	383	8.390	7.782	7.059	4.287	9.785	26.321	0.270	5.00	6.50	8.80	8.80	8.90
114	384	7.227	6.358	4.586	8.431	5.189	45.909	0.640	9.00	8.00	8.80	8.80	8.80
116	41	8.855	9.498	8.558	6.465	5.483	157.37	0.490	8.00	6.50	8.30	8.00	9.20

Appendix B

Table of Scores for the First and Second Lever Targets and a Rank Order of the Projects

Order	Number	Code	v	VA1	VB1	VB2	VA2	VC1	VC2	VC3
1	36	34	7.742	7.192	8.566	6.132	8.845	9.900	7.500	9.595
2	110	383	7.739	7.118	8.234	6.257	8.986	9.900	8.500	8.787
3	7	31	7.585	7.090	8.011	6.380	8.579	9.900	7.800	8.502
4	78	36	7.577	7.018	8.085	6.194	8.700	8.000	8.900	8.631
5	112	383	7.563	7.217	8.460	6.257	8.260	5.589	8.800	8.948
6	17	32	7.535	7.168	8.350	6.257	8.269	8.986	7.800	8.185
7	85	36	7.522	6.741	7.449	6.194	9.090	9.354	8.500	9.393
8	102	382	7.514	7.240	8.515	6.257	8.064	7.411	8.000	8.300
9	90	36	7.482	7.190	8.562	6.132	8.067	6.196	8.500	8.419
10	27	33	7.462	6.812	7.531	6.257	8.768	9.354	8.800	8.145
11	81	36	7.413	6.997	8.199	6.069	8.247	7.107	8.500	8.383
12	92	37	7.404	6.831	7.575	6.257	8.556	9.900	8.000	8.199
13	29	33	7.394	6.673	7.294	6.194	8.842	7.411	9.300	8.888
14	12	31	7.388	6.645	7.070	6.317	8.881	8.864	9.200	8.264
15	79	36	7.347	6.633	7.445	6.007	8.780	8.607	8.800	8.617
16	8	31	7.346	6.669	7.125	6.317	8.706	7.411	8.500	9.471
17	30	33	7.298	6.626	7.186	6.194	8.646	7.411	9.300	8.347
18	83	36	7.296	6.754	7.723	6.007	8.385	7.411	8.500	8.585
19	116	41	7.185	6.593	7.597	5.819	8.374	7.411	8.300	8.795
20	25	33	7.151	6.559	7.194	6.069	8.338	7.411	8.800	8.098
21	89	36	7.141	6.475	7.163	5.944	8.478	8.607	8.300	8.383
22	19	32	7.139	6.567	6.968	6.257	8.288	7.411	8.300	8.557
23	109	383	7.136	6.251	6.243	6.257	8.913	9.900	8.500	8.585
24	108	383	7.133	6.474	6.754	6.257	8.455	8.607	8.500	8.080
25	14	32	7.125	6.587	7.014	6.257	8.205	8.757	7.800	8.140
26	96	381	7.112	6.152	6.017	6.257	9.038	9.900	8.500	8.929
27	22	32	7.073	6.516	6.852	6.257	8.191	7.411	8.200	8.411
28	100	381	7.069	6.323	6.409	6.257	8.565	8.607	8.500	8.383
29	4	31	7.050	6.463	6.732	6.255	8.230	8.621	8.500	7.451
30	35	34	7.050	6.115	6.175	6.069	8.927	9.354	8.300	9.181
31	6	31	7.047	6.220	6.175	6.255	8.706	9.000	8.800	8.181
32	94	381	7.046	6.376	6.531	6.257	8.390	8.607	8.300	8.140
33	84	36	7.035	6.351	6.879	5.944	8.407	6.075	8.900	8.948
34	32	33	7.027	6.105	6.233	6.007	8.878	7.600	9.500	8.636
35	106	383	7.026	6.100	5.898	6.257	8.883	9.900	8.500	8.502
36	15	32	7.020	6.525	6.873	6.257	8.014	6.075	8.300	8.585
37	23	32	7.002	6.227	6.187	6.257	8.559	8.729	8.500	8.295
38	105	383	6.989	6.352	6.475	6.257	8.268	7.411	8.300	8.502
39	11	31	6.972	6.115	5.933	6.255	8.692	6.196	9.800	8.585
40	77	36	6.957	6.055	6.280	5.882	8.768	7.168	9.500	8.585
41	103	382	6.956	6.397	6.579	6.257	8.079	7.411	8.000	8.342
42	34	33	6.948	6.230	6.683	5.882	8.388	6.318	8.900	8.755
43	95	381	6.936	5.837	5.293	6.257	9.142	9.900	8.500	9.214
44	114	384	6.932	5.962	5.580	6.257	8.879	8.607	8.800	8.888
45	101	382	6.932	6.125	5.953	6.257	8.552	8.607	8.300	8.585
46	111	383	6.929	6.009	5.688	6.257	8.775	9.900	8.500	8.204
47	31	33	6.891	5.872	5.941	5.819	8.935	9.900	8.800	8.287
48	18	32	6.886	6.268	6.282	6.257	8.127	7.411	8.000	8.474
49	91	36	6.882	6.058	6.448	5.756	8.536	6.786	8.900	8.888
50	104	382	6.854	6.291	6.336	6.257	7.984	7.411	8.000	8.080
51	24	33	6.850	5.920	6.050	5.819	8.719	8.000	9.500	7.964

Order	Number	Code	v	VA1	VB1	VB2	VA2	VC1	VC2	VC3
52	82	36	6.825	6.048	6.507	5.694	8.385	7.411	8.500	8.585
53	97	381	6.818	6.078	5.847	6.257	8.302	5.589	9.300	8.466
54	10	31	6.771	6.041	5.844	6.192	8.237	8.182	8.800	7.368
55	33	33	6.754	5.943	6.104	5.819	8.382	6.500	9.000	8.512
56	20	32	6.702	5.948	5.710	6.132	8.214	7.411	8.200	8.474
57	61	35	6.692	5.323	6.708	4.255	9.440	8.607	9.500	9.595
58	9	31	6.677	6.078	6.174	6.004	7.878	7.289	8.100	7.411
59	87	36	6.665	5.884	6.456	5.444	8.231	6.075	8.800	8.585
60	43	35	6.655	6.110	8.596	4.192	7.751	5.771	70900	8.516
61	69	35	6.627	5.951	8.313	4.130	7.984	7.411	8.000	8.080
62	26	33	6.6.9	5.542	5.263	5.756	8.751	9.354	80800	8.098
63	46	35	6.600	5.638	7.673	4.067	8.533	7.593	8.500	8.888
64	99	381	6.568	5.722	5.028	6.257	8.268	7.411	8.300	8.502
65	75	35	6.544	5.601	7.671	4.004	8.435	8.607	8.300	8.264
66	1	31	6.536	5.707	5.322	6.004	8.200	8.818	9.000	6.656
67	54	35	6.507	5.411	7.235	4.004	8.708	8.607	8.300	9.016
68	3	31	6.491	5.626	5.134	6.004	8.230	8.621	8.500	7.451
69	80	36	6.488	5.345	5.380	5.318	8.780	8.607	8.800	8.617
70	62	35	6.446	5.481	7.477	3.942	8.381	8.607	8.000	8.474
71	51	35	6.442	5.189	6.805	3.942	8.958	9.900	8.300	8.948
72	38	34	6.381	5.352	4.422	6.069	8.446	8.568	7.900	8.795
73	66	35	6.370	5.234	7.072	3.817	8.560	7.411	8.800	8.709
74	2	31	6.323	6.246	6.559	6.004	6.478	6.318	7.600	5.050
75	64	35	6.315	5.052	6.734	3.754	8.852	9.354	8.800	8.378
76	21	32	6.287	5.695	5.129	6.132	7.475	7.411	7.500	7.277
77	50	35	6.282	4.702	5.929	3.754	9.454	9.900	9.200	9.237
78	41	35	6.235	4.719	6.051	3.692	9.280	9.900	8.500	9.595
79	65	35	6.187	4.945	6.570	3.692	8.679	9.354	8.500	8.259
80	28	33	6.176	4.991	4.405	5.444	8.556	7.411	9.300	8.098
81	70	35	6.173	5.156	7.053	3.692	8.216	8.607	7.800	8.259
82	68	35	6.161	5.072	6.861	3.692	8.346	8.607	8.000	8.378
83	59	35	6.153	5.076	6.871	3.692	8.316	8.607	8.000	8.295
84	86	36	6.117	5.043	5.902	4.380	8.273	8.607	8.100	8.057
85	48	35	6.090	5.151	7.205	3.566	7.974	6.500	8.000	8.585
86	56	35	6.065	4.987	6.828	3.566	8.230	8.607	8.000	8.057
87	71	35	6.034	5.040	7.030	3.504	8.029	7.411	8.000	8.204
88	73	35	6.027	4.834	6.559	3.504	8.421	8.607	8.000	8.585
89	57	35	5.981	4.682	6.208	3.504	8.591	9.900	8.000	8.295
90	47	35	5.954	4.810	6.502	3.504	8.253	8.607	8.000	8.121
91	76	35	5.868	4.647	6.292	3.379	8.319	8.304	8.300	8.121
92	67	35	5.844	4.536	6.035	3.379	8.471	7.411	8.500	8.823
93	74	35	5.808	4.469	5.882	3.379	8.497	9.000	8.300	8.204
94	40	35	5.776	4.549	6.065	3.379	8.239	8.686	7.900	8.15/8
95	58	35	5.690	4.124	5.090	3.379	8.834	9.000	9.000	8.295
96	53	35	5.572	3.776	4.452	3.254	9.180	8.607	9.200	9.237
97	63	35	5.563	3.889	4.712	3.254	8.923	9.354	8.500	8.933
98	49	35	5.498	4.104	5.286	3.191	8.296	8.607	8.000	8.241
99	44	35	5.493	4.090	5.256	3.191	8.310	9.900	7.500	8.121
100	55	35	5.450	3.989	5.024	3.191	8.381	8.607	8.000	8.474
101	42	35	5.420	4.044	5.232	3.129	8.181	8.182	8.000	8.171
102	45	35	5.186	3.629	4.277	3.129	8.313	8.607	8.000	8.287
103	60	35	4.977	3.314	3.718	3.003	8.316	8.607	8.000	8.295

Vita

Qing Li

Qing Li was born in Jilin, China on July 23, 1963. He received his BS and MS in Mathematics from Yanbian University and Institute of Mathematics at Chinese Academy of Science and his Ph.D. in Management Engineering from Xi'an Jiaotong University. He has published several articles in journals, was the winner of various national awards in China, and was the principal investigator on four projects sponsored by NSFC. He continued his education at the Virginia Polytechnic Institute and State University to pursue his Master of Science degree in Industrial and Systems Engineering.