

**STRATEGIC MANAGEMENT FOR LARGE ENGINEERING PROJECTS:
THE STAKEHOLDER VALUE NETWORK APPROACH**

by

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ABSTRACT

A critical element of the challenges and opportunities for today's large engineering projects are associated with the multi-type and networked relationships between these projects and their various stakeholders. This dissertation advances a multidisciplinary approach—Stakeholder Value Network (SVN) analysis—as a unique lens to examine, understand, model, and manage these stakeholder relationships.

The SVN approach, based on the Social Exchange Theory (SET), unifies both social and economic relationships into a common framework, under which all the stakeholder relationships are formed by the use of subjective utility analysis and the comparison of alternatives. Next, restricted and generalized exchanges are identified as two basic patterns for stakeholders to exchange both tangible and intangible value, and from this, the missing links between relationship types and exchange patterns are also discovered. In the end, the network implications, such as stakeholder importance or salience, are inferred as the outcome of both value exchanges and the structural properties of the network consisting of stakeholders and their exchange relationships.

According to the above theoretically grounded assumptions, a four-step methodological framework (viz., Mapping, Quantifying, Searching, and Analyzing) is developed for the SVN analysis. As part of this development, a network utility model is built to quantify the value delivered to the focal organization (viz., the large engineering projects) through the channel of generalized exchanges. Meanwhile, the benefits from as well as a feasible way for the integration of stakeholders and strategic issues are explored under the SVN framework. In addition, for the purpose of reducing the egocentric bias associated with the pre-selection of a focal organization, the four-step framework is further developed to interpret the implications of the SVN from the perspective of the whole network. The computational challenges arising from this new development are met by the construction of a dedicated mathematical tool for the SVN analysis, namely, the Dependency Structure Matrix (DSM) modeling platform.

Corresponding to the two-stage development of the methodological framework, two large real-world engineering projects are studied respectively:

The first one, Project Phoenix, is a retrospective case and applies the SVN analysis from the focal organization perspective. Based on this case study, the descriptive accuracy of the SVN analysis is validated, through a comparison of important stakeholders derived from Managers' Mental Model, the "Hub-and-Spoke" Model, and the SVN Model. Specifically, it is found that Managers' Mental Model is similar to the "Hub-and-Spoke" Model, and both models miss the Public Media and the Local Governments as important stakeholders at the beginning of the project. On the contrary, even with only prior information, the SVN Model identifies the importance of these two stakeholders by capturing the impacts of indirect stakeholder relationships as generalized exchanges. The reasons why generalized exchanges matter for today's large engineering projects are further examined from psychological, sociological, economic, and managerial aspects.

The second one, China's Energy Conservation Campaign, is a prospective case and applies the SVN analysis from the whole network perspective. In this case study, five basic principles are first proposed for modeling the intraorganizational hierarchies of large and important stakeholders, and then these principles are tested as an effective means to manage the structural complexity of the SVN in the modeling process. During this process, the instrumental power of the SVN analysis is demonstrated.

The SVN approach becomes complete with the above theory, methodology, tool, and meaningful findings from two representative case studies. At the end of this dissertation, two conceptual innovations are conceived to bridge the gap between the SVN analysis and systems architecting, and the theoretical, methodological, as well as empirical directions of future research on the SVN approach are also discussed.

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To my dear wife, parents, mentor, and buddy:

Yuan, Chunbai & Xianze, Ed, and Bruce

... The brightest lights in the blackest nights

为天地立心，
为生民立命，
为往圣继绝学，
为万世开太平。

张载 (1020~1077)

*Twenty years from now you will be more disappointed by
the things that you didn't do than by the ones you did do.*

So throw off the bowlines.

Sail away from the safe harbor.

Catch the trade winds in your sails.

Explore. Dream. Discover.

— *Mark Twain (1835~1910)*

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Ed is a brilliant scholar, not only in the important field studying how to put human on the Moon (or the Mars to be more recent), but also in the large and complex socio-technical systems behind and beyond those ambitious space missions. One of the most joyful moments in my Ph.D. life was actually to sit in Ed’s office and watch him to draw the tree of our academic family on the whiteboard: From Ludwig Prandtl (1875~1953) at the University of Göttingen, to Theodore von Kármán (1881~1963) and Qian Xuesen (a.k.a., Hsue-Shen Tsien, 1911~2009) at Caltech, and to Jack L. Kerrebrock at MIT, I always feel so honored to be connected with these great names, and meanwhile, these great names have strongly urged me to work very hard and bring more glory to our academic family. Especially, Professor Qian Xuesen, the father of China’s missile and space programs, first came to MIT in 1935 and later on has been highly regarded by all the Chinese people as a national symbol of outstanding scientists. Although it’s a pity that I didn’t become a cool rocket scientist like Professor Qian, I think our research did finally meet together in the interesting field of engineering systems. In fact, Professor Qian published his book *Engineering Cybernetics* in 1954, about the same time as Norbert Wiener’s *Cybernetics*, and then established the new discipline of systems engineering in China around the 1970s—in Professor Qian’s dictionary, the concept of “systems engineering” is very similar to our definition of “engineering systems” at ESD—he coined the name of “Open Complex Giant System” and also emphasized the critical roles of social sciences and management in fully understanding such an important system. From this perspective, Ed has made a similar transition from a traditional engineering discipline to the discipline of engineering systems and then to engineering leadership. Influenced by both professors, I hope I can also complete such a transition and explore more synergies between engineering, management, and social sciences to tackle the

challenges arising from today's complicated socio-technical systems, for a better tomorrow of the world.

Ed is a great teacher as well as a close friend to his students. No matter what kind of class, from Systems Architecture to Engineering Leadership, to Project Management, and to many other topics, Ed can surprisingly stimulate the curiosity of his students and we always feel there is a “magic” in his lectures. Outside of the classroom, Ed will invite his students to golf, ski, sail, and fly with him, and give the students lots of support far beyond their study and research. In the summer of 2008, when I conducted my second case study at Tsinghua University, Ed told me I should not stay in office days and nights, and then he bought an expensive ticket by himself and invited me to watch the closing ceremony of the Beijing Olympics (you can check out his Facebook for a wonderful picture taken by me, :P)!

Ed is also a visionary leader in engineering education and has very successfully led the Department of Aeronautics and Astronautics at MIT, the Cambridge-MIT Institute, the global CDIO Initiative, the Gordon Engineering Leadership Program, and currently the Skolkovo Institute of Science and Technology in Russia. Additionally, Ed is the living definition of entrepreneur, and he has founded a few private companies across a variety of high-tech industries. In a word, Ed has not only taught me the knowledge to be a good researcher, but the virtues to be a great man. I am really proud of having been Ed's student, and sincerely wish one day I can also make him proud.

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CHAPTER 1. INTRODUCTION

“Prometheus the creator, once restrained by defense projects sharply focused upon technical and economic problems, is now free to embrace the messy environmental, political, and social complexity of the postindustrial world.”

— Hughes [1998, p. 14]

1.1 Dissertation Motivation

1.1.1 Large Engineering Projects: Impacts and Challenges

Since the twentieth century, large engineering projects (LEPs), sometimes also termed as “megaprojects” [Flyvbjerg, Bruzelius, and Rothengatter, 2003] or “macro-projects” [Bolonkin and Cathcart, 2009], have become a remarkable phenomenon emerging from the interactions between human society and the natural environment, such as telephone networks, electric grids, national highways, oil fields, space stations, and so on. These phenomenal projects are made possible on the basis of technological advancement, especially after individual “inventions begin to be connected” [de Weck, Roos, and Magee, 2011, p. 3] into large and complex systems, and meanwhile, the impacts of these projects are in-depth and far-reaching from many perspectives.

There is no doubt about the substantial improvement brought by the LEPs on the quality of human life—for people living in the modern society, it is impossible to image going back to the old times, even only for one day, without the telephones, electricity, highways, and airports—several months ago, when Hurricane Sandy temporarily destroyed many infrastructures in the New York City, I witnessed by myself the chaotic

and helpless scenes of the whole city, resulting from the loss of water, electricity, public transportation, and many other benefits closely associated with the LEPs.

Additionally, when examined at the macro-level, LEPs “constitute one of the most important business sectors in the world” [Miller and Lessard, 2001, p. 1]. It is evident that there exists a strong connection between LEPs and the productivity growth and national competitiveness of a country [Hirschman, 1957]. On one hand, for the developed countries, such as the United States, this connection is apparent “because advanced industrial societies in the West dealt with their infrastructure needs through a mixture of centralized public bureaucracies, regional governments, and private firms” [Miller and Lessard, 2001, p. 2]. On the other hand, for the developing countries, such as China [Démurger, 2001], the role of LEPs in modernization makes that connection even clearer and more important. For example, in 1993, China’s capital investment on LEPs already reached 6.5% of the GDP of that year [World Bank, 1995]; and after more than ten years, by the end of 2009, the LEPs investment had even reached 15% ~ 20% of the GDP for coastal provinces and all four municipalities in China [Shi, 2012]. Moreover, for both the developed and developing countries, during the period of economic slowdown or crisis, LEPs have been widely taken as an effective policy measure to stimulate the general economy, such as the well-known Roosevelt’s New Deal in the 1930s, and more recent examples include the 2008-2009 Chinese Economic Stimulus Program, the 2008 European Union Stimulus Plan, as well as the American Recovery and Reinvestment Act of 2009.

However, every coin has two sides—accompanying with the above positive impacts, LEPs also bring potential externalities (i.e., the overuse of natural resources, environmental pollutions, etc.) as well as unintended consequences (i.e., traffic congestions, power outages, etc.). Further, because of their scale and complexity, LEPs are difficult to shape and execute and often go terribly wrong¹, with serious implications

¹ For example, the Central Artery/Tunnel Project (CA/T) or the “Big Dig” in Boston, Massachusetts (http://en.wikipedia.org/wiki/Big_Dig): This project was the most expensive highway project in the U.S. and has been plagued by escalating costs (\$5.3 billion or 190% more than the estimated cost, in 1982 dollars), scheduling overruns (completed in December 2007,

for their sponsors and other stakeholders. Because of the magnitude of capital investment for as well as broad spatial and temporal scope of LEPs, the negative impacts of those externalities and consequences on human society are often severe, long-lasting, and even irreversible. In return, with the increasing recognition of these possible negative impacts, LEPs face the social, political, and legal oppositions from a wide range of stakeholders, which in turn becomes a more common reason leading to the failure of the projects. For example, since the 1960s, mass mobilization has taken place against the construction of inner city freeways in the United States, nuclear power plants in Germany, new airports in Mexico City, and oil pipelines in Africa. This stakeholder opposition becomes even more difficult to handle for the LEPs that cross the borders of countries with different social and political systems, such as Russia's environmental ban in August 2006 imposed on Royal Dutch Shell's multi-billion offshore oil projects the Sakhalin-II [Parfitt, 2006], which was financed by the European Bank for Reconstruction and Development (EBRD) at that time. McAdam, Boudet, Davis, et al. [2011, p. 401] once synopsized this way: "Fifty years ago, the main challenges to large infrastructure projects were technical or scientific. Today, the greatest hurdles faced by such projects are almost always social and / or political."

Meanwhile, "in parallel with the growth of physical infrastructure came an increase in the size of the firms and organizations that ran these systems" [de Weck, Roos, and Magee, 2011, p. 7]. Further, with the increase in the size of the firms running LEPs, the emergence of organizational hierarchy and heterogeneity adds even more difficulties to efficiently design and effectively manage these projects surrounded by various stakeholders, "who can affect and are affected by" [Freeman, 1984] the long-term success of these large projects—in the dissertation, the "long-term success" specifically means "creating as much value as possible for stakeholders, without resorting to trade-offs" [Freeman, Harrison, Wicks, et al., 2010, p. 28]. As highlighted by Miller and Lessard [2001, p. 3]: "The gap between the realities of projects and theories for managing them is

about ten years later than the original schedule), and worsening performance (such as leaks, design flaws, charges of poor execution and use of substandard materials, criminal arrests, and even one death).

widening. The metaphor of rational planning, beginning with a complete project description that is broken down into a myriad of pre-specified tasks, is largely inadequate for describing what is now happening in LEPs.”

Together, the above exogenous and endogenous changes pose unprecedented challenges for strategic management of today’s LEPs, which generate the first motivation of this dissertation.

1.1.2 “Rescuing Prometheus”: The Quest for A Multi-disciplinary Approach

The renowned book written by Thomas Hughes [1998], *Rescuing Prometheus: Four Monumental Projects that Changed Our World*, was among the earliest treatises on new challenges for the management of LEPs. At the beginning of his book, Hughes [1998, p. 4] asserted that: “The reader may be surprised to find this history of technological projects focusing so often upon management rather than upon the engineering and science being managed”, and he also believed that “the engineers and scientists managing the projects have often found that management has presented more difficult challenges than research and development.”

Hughes’ assertion validates the first motivation of this dissertation. However, we also realize that there exists no silver bullet to cope with the exogenous and endogenous changes faced by LEPs, and in fact, a multi-disciplinary approach is much needed to rescue “Prometheus the creator” from “the messy environmental, political, and social complexity of the postindustrial world” [Hughes, 1998, p. 14]. Nowadays, there is an increasing consensus among engineers, managers, policymakers, and other stakeholders that the growing complexity of LEPs consists of the technical, managerial, and social dimensions, which are closely interwoven together and often evolving in a dynamic way. Therefore, in order to better manage the turbulence for LEPs behind these complexities, the desired multi-disciplinary approach should have three pillars: engineering, management, and social sciences.

The quest for such an approach directly incubates the “Engineering Systems” as an important and promising new field [Moses, 2004a; de Weck, Roos, and Magee, 2011], which is discussed in detail in Chapter 2. Meanwhile, this epic quest also stimulates the second motivation of this dissertation.

1.2 Research Questions

It should be clearly realized that the above two ambitious goals, either managing the exogenous and endogenous turbulence of LEPs or developing a multi-disciplinary approach for that purpose, can by no means be completely achieved in one single doctoral dissertation, or even by several prestigious university departments, such as the Engineering Systems Division (ESD) at MIT, the Department of Management Science and Engineering (MS&E) at Stanford, and the Department of Engineering and Public Policy (EPP) at CMU. Instead, these goals belong to the “endless frontier” [Bush, 1945] of engineering science, and the achievement of the goals requires the devoted contributions of many generations in all the related disciplines and practices.

That being said, we embark on this voyage by looking into the multi-type and networked relationships between LEPs and their stakeholders—as one of the three founding architects of sociology, Max Weber (1864~1920) treated “sociology as first and foremost about relationships” [Scott and Calhoun, 2004, p. 10]—influenced by Weber’s treatment, we are striving to find the answers to the following questions:

- **Question One:** *What are the basic types of the relationships between LEPs and their stakeholders? Is it possible to analyze different types of stakeholder relationships together?*

- **Question Two:** *What are the basic patterns for value exchanges among LEPs and their stakeholders through these relationships? Is there any connection between the exchange patterns and the relationship types?*
- **Question Three:** *Can we interpret the implications emerging from the multi-type and networked relationships between LEPs and their stakeholders? Can we use these insights to formulate strategies in a positive and proactive way as well as with manageable complexity? Can we use these insights to inform the process of system architecting?*
- **Question Four:** *Based on the answers to the above questions, can we develop a methodological framework, with the support of an effective and efficient modeling tool, to perform a comprehensive analysis for the multi-relational network consisting of LEPs and their stakeholders?*
- **Question Five:** *Can we apply the above theory, methodology, and tool to the LEPs in the real world? Can the theory, methodology, and tool be validated by as well as shed light on the real-world case studies?*

Note that the first three questions are centered on the theoretical foundation of this dissertation; the fourth question puts forward the need for a methodological framework as well as a modeling tool; and the last question requires the theory, methodology, and tool to be tested by case studies.

We will argue that the answers to these questions must rely on a multi-disciplinary approach across engineering, management, and social sciences. We also will show that the multi-disciplinary approach of Stakeholder Value Network (SVN) contributes to the existing knowledge in all three disciplinary domains.

1.3 Dissertation Architecture

Figure 1-1 sketches the overall architecture of this dissertation:

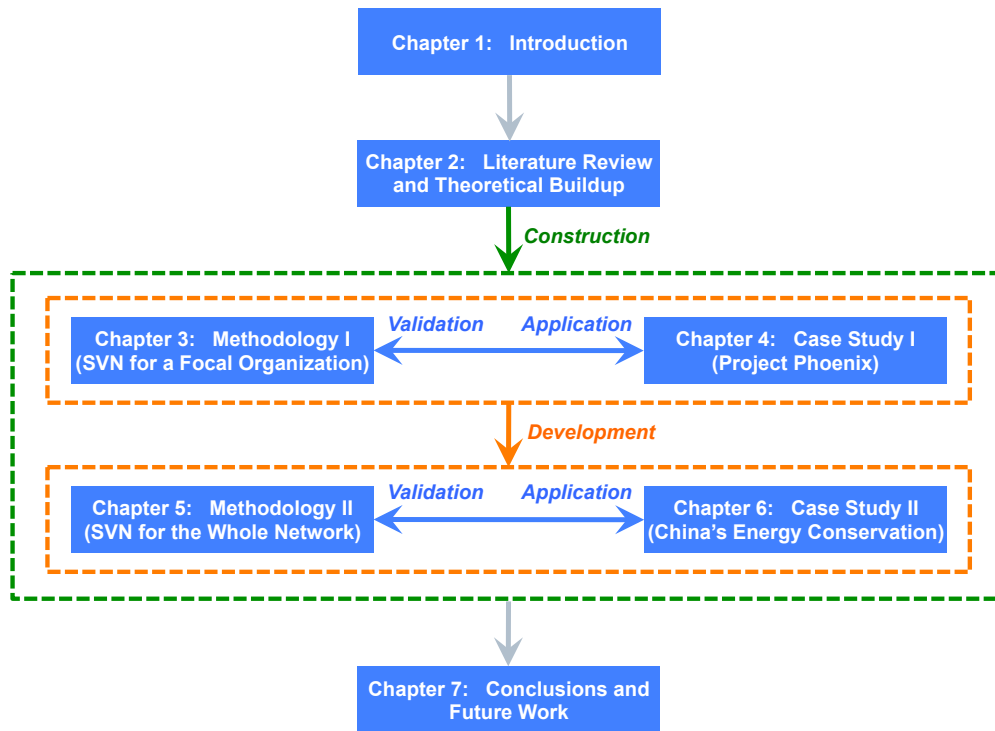


Figure 1-1: Dissertation Architecture

Based on Figure 1-1, the remainder of this dissertation is organized as follows:

- **Chapter 2** reviews the relevant literature in strategic management, engineering systems, as well as the network analysis of social sciences. Based on the literature review, the theoretical foundation for Stakeholder Value Network (SVN) is built up, and more specific research opportunities arising from each discipline are also identified.
- **Chapters 3 ~ 6** constitute the main body of this dissertation, which can be divided into two modules: Chapters 3 and 4 form the first module and explore the implications of the Stakeholder Value Network (SVN) from the perspective of a focal organization, while Chapters 5 and 6 form the second module and explore

the implications of the Stakeholder Value Network (SVN) from the perspective of the whole network. Further, Chapter 3 develops the methodology applied in the case study of Chapter 4, and meanwhile, the case study of Chapter 4 validates the methodology developed in Chapter 3. Organized in the same way, Chapters 5 and 6 stand on the work completed by Chapters 3 and 4, and also build a modeling tool dedicated to the Stakeholder Value Network (SVN) analysis.

- **Chapter 7** concludes with the main contributions of this dissertation and also suggests a few directions for future research.

In addition, **Appendix I** further extends the Stakeholder Value Network (SVN) approach to the architecting process for LEPs as well as engineering systems in general.

CHAPTER 2. LITERATURE REVIEW AND THEORETICAL BUILDUP

“Many have argued that the business world of the twenty-first century has undergone dramatic change. The rise of globalization, the dominance of information technology, the liberalization of states, especially the demise of centralized state planning and ownership of industry, and increased societal awareness of the impact of business on communities and nations have all been suggested as reasons to revise our understanding of business.”

— Freeman, Harrison, Wicks, et al. [2010, p. 3]

2.1 Chapter Introduction

Following the above background and motivations, this chapter conducts a thorough investigation on the academic literature in the Stakeholder Theory, Engineering Systems, as well as the Network Analysis in Social Sciences. Along with the literature review, research opportunities to better answer the important questions raised in the last chapter are identified, and through this process the theoretical foundation for this dissertation is also built up, culminating in the definition of and three key assumptions for the Stakeholder Value Network (SVN). Specifically, Figure 2-1 illustrates the roadmap for literature review and theoretical buildup in this chapter.

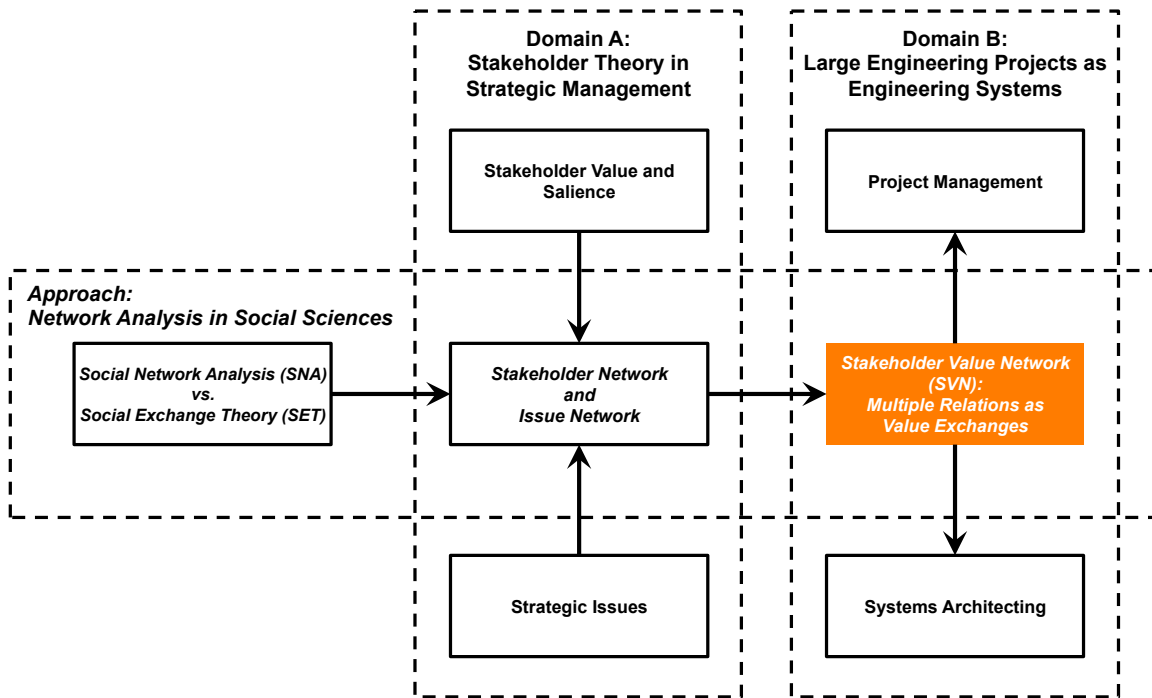


Figure 2-1: Roadmap for Literature Review and Theoretical Buildup

2.2 Domains: Strategic Management and Engineering Systems

2.2.1 Stakeholder Theory in Strategic Management

In the past thirty years, since the publication of Edward Freeman’s path-breaking book, *Strategic Management: A Stakeholder Approach* [1984], a new branch in Strategic Management known as “Stakeholder Theory” has been significantly advanced and “its descriptive accuracy, instrumental power, and normative validity” have also been widely justified [Donaldson and Preston, 1995, p. 65].

As an extension of the concept of “stockholder”, which for a long time has been treated as the only group to whom corporate management needs be responsive in theories and practices, the word “stakeholder” was first coined in an internal memorandum at the Stanford Research Institute in 1963, referring to “those groups without whose support the organization would cease to exist” [Freeman, 1984, p. 31]. This definition was then

refined in a more neutral and comprehensive way: a “stakeholder” for an organization is “any group or individual who can affect or is affected by the achievement of the organization’s objectives” [Freeman, 1984, p. 46], and Freeman clearly stated the motivation behind the emergence of “stakeholder” is to better understand and cope with the dramatic changes of the environment for modern corporations, such as “the rise of globalization, the dominance of information technology, the liberalization of states, especially the demise of centralized state planning and ownership of industry, and increased societal awareness of the impact of business on communities and nations” [Freeman, Harrison, Wicks, et al., 2010, p. 3].

Since its inception, the concept of “stakeholder” has challenged and been challenged by the dominant schools in business and management, which are mainly based on the economic ideal of an orderly movement towards the market equilibrium, with the assumption that corporations are the property of their owners (viz., stockholders for public companies) and their liability for their effects upon others is limited. Freeman and other stakeholder scholars argued that the above basis and assumption do not always hold, especially under the turbulent environment for modern corporations, and they further proposed to ground the Stakeholder Theory in a Philosophical Pragmatism [Rorty, 1979; Wicks and Freeman, 1998] and made an explicit tie to the Theory of Entrepreneurship [Venkataraman, 1997; 2002]. In addition, Freeman, Harrison, Wicks, et al. [2010, pp. 10-19] also argued the main ideas of Stakeholder Theory are still compatible with a number of other popular schools in business and management: the Free Market approach of Milton Friedman [1962; 1970], the Agency Theory approach of Michael Jensen [2001; Jensen and Meckling, 1976], the Competitive Advantage approach of Michael Porter [1985], and the Transaction Cost theory of Oliver Williamson [1973; 1975; 1981].

Further, Donaldson and Preston [1995, pp. 66-67] divided the existing research on Stakeholder Theory into three categories:

- **Descriptive Stakeholder Theory:** This category of stakeholder research presents a model that “describes the corporation as a constellation of cooperative and competitive interests possessing intrinsic value”;
- **Instrumental Stakeholder Theory:** This category of stakeholder research “establishes a framework for examining the connections, if any, between the practice of stakeholder management and the achievement of various corporate performance goals”;
- **Normative Stakeholder Theory:** This category of stakeholder research provides the fundamental basis for Stakeholder Theory by assuming that “stakeholders are persons or groups with legitimate interests in procedural and/or substantive aspects of corporate activity”, and “the interests of all stakeholders are of intrinsic value.”

Examples of Descriptive Stakeholder Theory can be found in Friedman and Miles [2002], Mitchell, Agle, and Wood [1997], and Rowley [2003] among others. Examples of Instrumental Stakeholder Theory can be found in Agle, Mitchell, and Sonnenfeld [1999], Harrison, Bosse, and Phillips [2010], Harrison and St. John [1996], Jones [1995], Rowley [1997], Scott and Lane [2000], Slinger [1999], and Wheeler and Sillanpää [1998] among others. Finally, examples of Normative Stakeholder Theory can be found in Clarkson [1995], Evan and Freeman [1993], Hillman and Keim [2001], Phillips [1997], and Wheeler, Colbert, and Freeman [2003] among others. In addition, some scholars [Donaldson, 1999; Freeman, 1999; Jones and Wicks, 1999; Treviño and Weaver, 1999] also proposed to develop a Whole Stakeholder Theory by integrating all the above three categories.

Specifically, Freeman, Harrison, Wicks, et al. [2010, p. 6] argued that the distinctions given by Donaldson and Preston [1995] are not useful all the time, because Stakeholder Theory should be inherently “managerial”. Based on this argument, Freeman, Harrison, Wicks, et al. [2010, pp. 4-5 and p. 29] outlined three basic problems that Stakeholder Theory has evolved to address over decades:

- **The Problem of Value Creation and Trade:** Understanding and managing a business in the world of the twenty-first century—for instance, “How can we understand business in a world where there is a great deal of change in business relationships, and where these relationships shift depending on the national, industry, and societal context?” and “How is value creation and trade possible in such a world?”
- **The Problem of the Ethics of Capitalism:** Putting together thinking about questions of ethics, responsibility, and sustainability with the usual economic view of capitalism—for instance, “How can we understand capitalism so that all its effects can be taken into account by decision makers, rather than externalized on society?” and “Is it possible for business executives to ‘do the right thing’, all things considered, no matter how complicated the world is?”
- **The Problem of Managerial Mindset:** Understanding what to teach managers and students about what it takes to be successful in the current business world—for instance, “How can we utilize and redefine economic theory so that it becomes useful in a turbulent world full of ethical challenges?” and “How can managers adopt a mindset that puts business and ethics together to make decisions on a routine basis?”

2.2.2 Research Opportunities for Stakeholder Theory

On the basis of the above literature review for Stakeholder Theory, against the backdrop of Strategic Management, we identify three major opportunities to contribute to the stakeholder research in the management domain: **Stakeholder Salience**, **Stakeholder Network Model**, as well as **Stakeholders and Strategic Issues**. Note that these three opportunities are organized by their logical depth, and mainly focus on the first and third problems (viz., Value Creation & Trade and Managerial Mindset) studied by the Stakeholder Theory [Freeman, Harrison, Wicks, et al., 2010, pp. 4-5 and p. 29]. In addition, if using the terminology defined by Donaldson and Preston [1995, pp. 66-67], these opportunities should be closer to the descriptive and instrumental categories than the normative one.

2.2.2.1 Stakeholder Salience

Freeman [1994, p. 411] once suggested using “Who and What Really Counts” as the principle to identify the stakeholders for an organization, which is often the first challenge for scholars and practitioners to understand and apply the Stakeholder Theory. However, there was little agreement on the specific contents of this principle. To meet this challenge, Mitchell, Agle, and Wood [1997] developed a descriptive theory of Stakeholder Salience and then validated its strength with an empirical study for CEO’s (Chief Executive Officers) decisions [Agle, Mitchell, and Sonnenfeld, 1999]. In their theory, Stakeholder Salience is defined as “the degree to which managers give priority to competing stakeholder claims” [Mitchell, Agle, and Wood, 1997, p. 854], and can be determined by managers’ perceptions of three key stakeholder attributes, namely, Power, Legitimacy, and Urgency:

- **Power:** A can get B to do something that B would not have otherwise done;
- **Legitimacy:** The actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions;
- **Urgency:** The degree to which stakeholder claims call for immediate attention.

Through combining the above three attributes, a comprehensive topology of seven categories of stakeholders is generated (see Figure 2-2): those stakeholders having only one attribute are called Latent Stakeholders (i.e., Category 1, 2, and 3), those stakeholders having two attributes are called Expectant Stakeholders (i.e., Category 4, 5, and 6), and those stakeholders having all of the three attributes are called Definitive Stakeholders (i.e., Category 7). From the latent to expectant and to definitive stakeholders, their importance perceived by managers, or the Stakeholder Salience, is increasing.

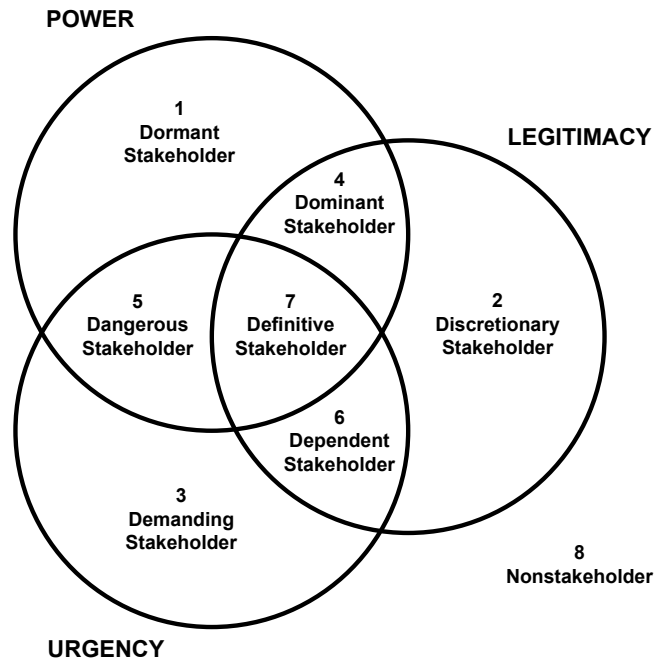


Figure 2-2: Stakeholder Typology [Adapted from Mitchell, Agle, and Wood, 1997, p. 874]

However, as emphasized by Freeman, Harrison, Wicks, et al. [2010, pp. 5-6]: “Stakeholder theory suggests that if we adopt as a unit of analysis the relationship between a business and the groups and individuals who can affect or are affected by it, then we have a better chance to deal with these three problems” (viz. the problems outlined in Section 2.2.1), we argue that it is more appropriate for the Stakeholder Salience theory to take the relationships between stakeholders, rather than stakeholders themselves, as the basis to understand the attributes of Power, Legitimacy, and Urgency, as well as the resulting Stakeholder Salience. The reason for this argument is mainly threefold:

- First of all, in light of the complexity of stakeholder relationships, it is not realistic to discuss the Power, Legitimacy, and Urgency of a stakeholder without considering the specific contents of relationships between this stakeholder and other stakeholders (including the focal organization). For example, Stakeholder A is more powerful than Stakeholder B in terms of issuing the environmental permits for Stakeholder B to conduct a large engineering project, but meanwhile Stakeholder B gains more power by creating more jobs and boosting the local

economy for Stakeholder A, and even more complicated, the power associated with different relationships is not always the same and may come into play during different period of the activity of a focal organization. The treatment is oversimplified to measure the Power, Legitimacy, and Urgency on the basis of stakeholders other than the relationships between stakeholders.

- Specifically, “a meaningful discussion of power really requires networks rather than dyads—precisely because dyadic relationships lack the social alternatives which are central to Emerson’s conception of power (Cook and Emerson, 1978)” [Cook, Cheshire, and Gerbasi, 2006, p. 197]. From the perspective of economics, “Power” is a secondary and derivative phenomenon determined by exchange relationships.
- Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005], which will be discussed in detail later this chapter, further points out that “Power” emerges and evolves in a complex structure of exchanges of resources—Collins [1988, p. 412] once elaborated in this way: “Human beings have the capacity to create and negotiate whatever they can at any moment in time. But they always act in a structured situation, so that the consequences and conditions of their creativity and negotiation are nevertheless patterned by larger relationships beyond their control.” Therefore, more in-depth research is desired to better interpret the “Power” of stakeholders, and we propose to base such an interpretation on the exchange relationships between stakeholders as well as the structural properties emerged from these relationships.

In fact, at the beginning of their seminal paper, Mitchell, Agle, and Wood [1997, p. 853] also recognized that Power, Legitimacy, and Urgency are three “relationship attributes”, but the logical consistency seemed lost later on, and they did not clearly map these attributes to stakeholder relationships, nor did they touch the complexity of understanding the multi-type and networked relationships between stakeholders.

2.2.2.2 Stakeholder Network Model

Once the stakeholder relationship is taken as the unit of analysis, the next interesting question will be how to build a stakeholder model to describe these relationships for informed decision-making. Rowley [1997] was among the first researchers to introduce the network approach of social sciences to the modeling of stakeholder relationships—specifically, he highlighted the limitation of concentrating on dyadic relationships between individual stakeholders and a focal organization, and then applied the Social Network Analysis (SNA), which will be discussed in detail later this chapter, to construct “a theory of stakeholder influences, which accommodates multiple, independent stakeholder demands and predicts how organizations respond to the simultaneous influence of multiple stakeholders” [Rowley, 1997, p. 887].

Before discussing the limitation of the traditional stakeholder model only focusing on dyadic relationships, like the “Hub-and-Spoke”, as well as the improvement on Rowley’s proposal for stakeholder network model, we first review the management literature on the modeling of modern firms (and their stakeholders), and classifies its development into five stages, from the earliest to the latest: the Production Model, the Managerial Model, the Stakeholder Model, the Single-Relational Stakeholder Network Model, and the Multi-Relational Stakeholder Network Model (see Figures 2-3 ~ 2-7 for simplified example of each model). Note that (1) the Production Model is also known as the Input-Output Model [Donaldson and Preston, 1995, p. 68]; (2) the Managerial Model is actually the Mental Model [Denzau and North, 1994, p. 4] shared by firms’ managers; (3) the Stakeholder Model is first constructed by Freeman [1984, p. 25] and then renamed as the “Hub-and-Spoke” Model by Donaldson and Preston [1995, p. 69]; (4) the Single-Relational Stakeholder Network Model refers to the Social Network Analysis (SNA) Model proposed by Rowley [1997, p. 891]; and (5) the Multi-Relational Stakeholder Network Model refers to the Stakeholder Value Network (SVN) Model developed by this dissertation and its forerunners [Cameron, 2007; Sutherland, 2009].

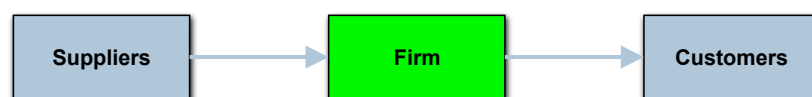


Figure 2-3: The Production Model of the Firm [Freeman, 1984, p. 5, Exhibit 1.1]

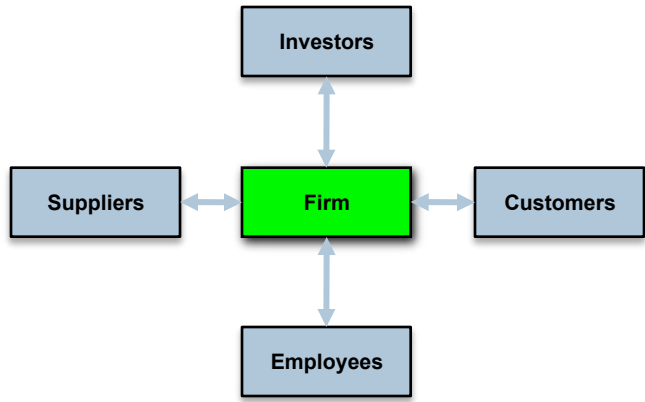


Figure 2-4: The Managerial Model of the Firm [Freeman, 1984, p. 6, Exhibit 1.2]

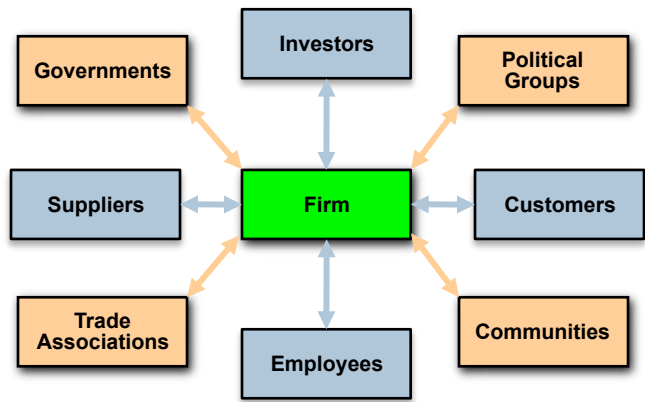


Figure 2-5: The "Hub-and-Spoke" Stakeholder Model of the Firm [Freeman, 1984, p. 25, Exhibit 1.5]

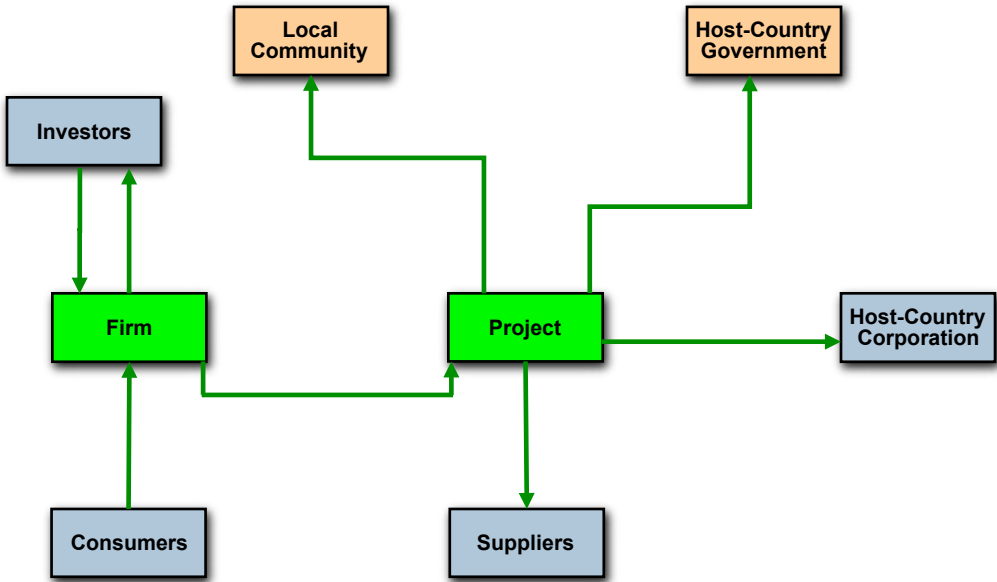


Figure 2-6: The Single-Relational Stakeholder Network Model of the Firm

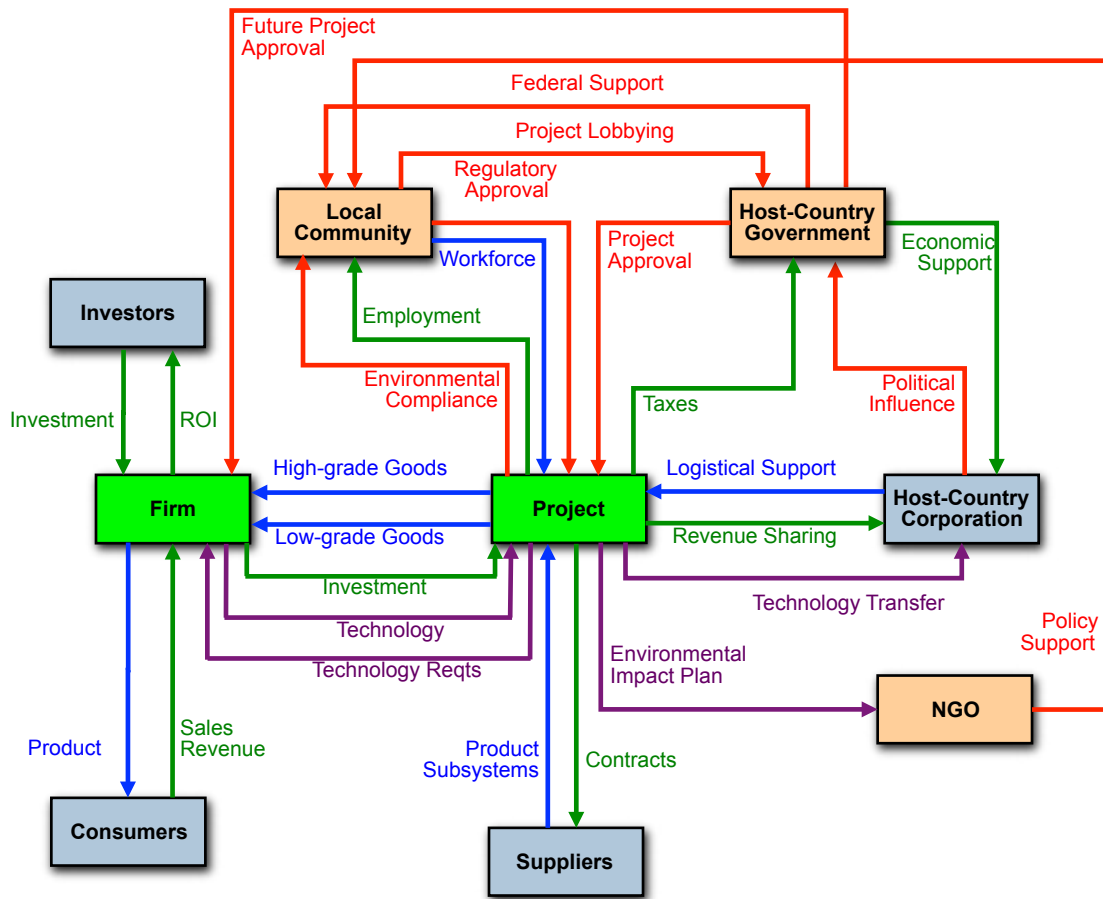


Figure 2-7: The Multi-Relational Stakeholder Network Model of the Firm

From Figure 2-3 to Figure 2-7, we observe that the models become more and more sophisticated in terms of the number of stakeholders and relationships as well as their contexts. Specifically, (1) the evolution from the Production Model to the Managerial Model depicts the separation of ownership and control from family-dominated business to modern firms; (2) the advancement from the Managerial Model to the Stakeholder Model highlights the internal and external changes in firms' market and nonmarket environments (especially in the "nonmarket" [Baron, 1995] one) during the past a few decades; (3) the progress from the Stakeholder Model to the Network Model reflects the current trend of moving the "units of analysis" [Freeman, Harrison, Wicks, et al., 2010, pp. 5-6] from the actors to the networked relationships between these actors, which are more fundamental phenomena as argued by sociologists [Emerson, 1976, p. 346; Firth,

1967, p. 4; Sahlins, 1965b, p. 139] and are also more holistic from the perspective of engineering systems [Cameron, 2007; Feng, Crawley, de Weck, et al., 2010; Sutherland, 2009]; and (4) for the two different network models, compared to the Social Network Analysis (SNA), the Stakeholder Value Network (SVN) developed in this dissertation aims to study the interactions between the multiple types of stakeholder relationships, particularly those indirect ones, as well as the resulting strategic implications. More detailed comparison between SNA and SVN will be elaborated later in this chapter.

It has been almost sixteen years since Rowley's proposal for applying the network analysis (more specifically, the Social Network Analysis or SNA), but nowadays the "Hub-and-Spoke" Model (see Figure 2-5) is still the dominant paradigm of stakeholder model, possibly because of the lack of a sounder theoretical foundation, a more comprehensive methodological framework, a more powerful modeling tool, as well as more empirical case studies—all these possible reasons suggest promising research opportunities for this dissertation.

2.2.2.3 Stakeholders and Strategic Issues

Based on the above classification for the development of firm models, another interesting observation is that in moving from the Managerial Model (see Figure 2-4) to the "Hub-and-Spoke" Stakeholder Model (see Figure 2-5), the added actors, Governments, Political Groups, Trade Associations, and Communities, all come from the "nonmarket" environment, in contrast to the traditional "market" environment which includes Investors, Suppliers, Customers, and Employees. This observation indicates the strong connections between Stakeholder Theory and the research on Nonmarket Strategy [Baron, 1995, 2001; Boddewyn, 2003; Kanter, 1999; Mahon, Heugens, and Lamertz, 2004].

Actually, as highlighted by Lucea [2007, p. 17], in the research of Nonmarket Strategy, Stakeholder Theory is often treated as a rival approach to "Issue Management" or "Strategic Issue Management" [Ansoff, 1980; Arcelus and Schaeffer, 1982; Bartha, 1983;

Bigelow, Fahey, and Mahon, 1991, 1993; Chase, 1982, 1984; Dutton and Duncan, 1987; Johnson, 1983; Mahon and Waddock, 1992]. “Issues” are usually defined as “events, trends, or developments that could have a negative impact on the organization’s ability to reach its objectives if left unattended” [Mahon, Heugens, and Lamertz, 2004, p. 171], or more accurately, “focal and concrete events such as a project, a product, or a firm policy that generate gaps between the expectations of a number of stakeholders and the firm’s behavior” [Lucea, 2007, p. 26]. Specifically, Table 2-1 compares the objective, focus, and research emphasis of Stakeholder Theory and Strategic Issue Management.

Table 2-1: Comparison between Stakeholder Theory and Strategic Issue Management
[Adapted from Lucea, 2007, p. 24]

	<i>Stakeholder Theory</i>	<i>Strategic Issue Management</i>
<i>Objective</i> [Mahon, Heugens, and Lamertz, 2004]	Appease critical actors; Foster cooperation	Minimize surprises; Risk management approach
<i>Focus</i> [Mahon, Heugens, and Lamertz, 2004]	Individuals, groups, communities, organizations	Events, trends
<i>Research Emphasis</i>	Stakeholder identification; Stakeholder classification; Stakeholder salience	Issue life cycles; Evolution of issues; Strategic responses at different stages
<i>Paradigm Critiques / Shortcomings</i>		
<u><i>Intertwining of Issues and Stakeholders:</i></u>		
<ul style="list-style-type: none"> • Stakeholder: May be involved in multiple issues [Mahon, Heugens, and Lamertz, 2004]; • Issues: Interaction of multiple issues may deviate from normal path [Bigelow, Fahey, and Mahon, 1991, 1993]. 		
<u><i>Type of Relation:</i></u>		
<ul style="list-style-type: none"> • Stakeholders: The relationship between firm and a given stakeholder may vary by issues • Issues: Issues may be subsumed in other issues [Marres and Rogers, 2004] or may be at different life cycle stages [Mahon and Waddock, 1992] • Attributes vs. Relationships: Most research is based on attributes of stakeholders or issues rather than the relationships among them [Rowley, 1997] 		
<u><i>Unit of analysis:</i></u>		
<ul style="list-style-type: none"> • Appropriate unit of analysis is firm-issue-stakeholder triplet [Eesley and Lenox, 2006] 		

As shown in the above table, although there are many differences between Stakeholder Theory and Strategic Issue Management, several constructive proposals (listed in order of

publication) have been put forward to integrate these two fields, especially using the network approach from social sciences, in order to gain more synergy and make better decisions:

- Mahon, Heugens, and Lamertz [2004] employed the Social Network Analysis (SNA) to make “a number of theoretically grounded conjectures about the delicate relationships between stakeholder behavior and issue evolution” [Mahon, Heugens, and Lamertz, 2004, p. 170];
- Lucea [2007] developed the concept of “global issue space” as an integrative framework that “helps make sense of the multiple relations established between a focal firm and its stakeholders across issues and geographies” [Lucea, 2007, p. 16];
- Roloff [2008] identified two types of stakeholder management in the practice of modern corporations, that is, “organization-focused” and “issue-focused”, and then demonstrated that “issue-focused stakeholder management dominates in multi-stakeholder networks” [Roloff, 2008, p. 233];
- Frooman [2010] introduced the idea of an “issue network”, and argued that “members of an issue network can be identified as those with grievances, resources, or opportunities” [Frooman, 2010, p. 161], by drawing on concepts from the fields of social movements (sociology) and interest groups (political science).

We find that the above proposals are still in the early stage of forging the ties between stakeholders and issues—most of them only focus on justifying the need of integration, developing theoretical hypotheses, and/or building descriptive models. More importantly, except the proposal from Lucea [2007], other three neither provide an analytical and instrumental framework, nor address the importance of a multi-relational approach. These limitations show more directions for us to make contributions.

2.2.3 Large Engineering Projects as Engineering Systems

Parallel to the emergence of stakeholder theory in management domain as an effort to understand dramatic change of the environment for modern corporations, engineers—the professionals who design, build, maintain, and optimize large engineering projects—are also revising their understanding for today’s engineering discipline.

After the World War II, with Vannevar Bush’s landmark report, *Science: The Endless Frontier* [1945], engineering formally became a science-based discipline. Since then, the “epoch of great inventions and artifacts” has quickly progressed to the “epoch of complex systems” [de Weck, Roos, and Magee, 2011, p. 14, Figure 1.2]. However, “the systems of this epoch grew to become not only technically complex but also socially complex” [de Weck, Roos, and Magee, 2011, p. 28], and this great challenge finally gave birth to “engineering systems”, the next stage of engineering discipline following the epoch of complex systems.

The Massachusetts Institute of Technology (MIT) was the birthplace of engineering systems—based on the efforts of several generations, from Norbert Wiener to Charles Miller, to Daniel Roos, and to today’s scholars and students at the Engineering Systems Division (ESD hereafter)—engineering systems is currently “taking shape as a global phenomenon” [de Weck, Roos, and Magee, 2011, p. xv].

Arguably, the most striking feature differentiating engineering systems from traditional engineering fields is the in-depth combination of theories and approaches from engineering, management, and social sciences [ESD Symposium Committee, 2006, p. 2] to answer questions with far-reaching importance and related to the sociotechnical systems—large engineering projects obviously belong to such kind of systems, which are “characterized by a high degree of technical complexity, social intricacy, and elaborate processes, aimed at fulfilling important functions in society” [de Weck, Roos, and Magee, 2011, p. 31].

Specifically, rooted in the management domain, stakeholder theory has already seen many useful applications in the research conducted at ESD. A thorough investigation on

these applications can help identify research opportunities for managing the stakeholders for large engineering projects as well as ensuring the “long-term success” [Freeman, 1984] of these projects.

2.2.4 Research Opportunities for Engineering Systems

Table 2-2 summarizes the stakeholder-related research conducted at ESD (including its preceding programs, such as the Technology and Policy Program) in the past twenty years. Although this list is by no means complete, its length does confirm “stakeholder” as a focus of pioneering research in the field of engineering systems. More importantly, we will demonstrate that the selected 24 theses and papers (listed in the publication order) are sufficient to identify the patterns, limitations, as well as trends of the interdisciplinary research between stakeholder theory and engineering systems.

Table 2-2: Stakeholder Research at MIT ESD (Listed in the Publication Order)

	Theoretical Bases			Contributing Areas			Methodological Foci		Case Studies					
	System Theories	Stakeholder Theory	Social Sciences	Engineering Systems	Corporate Strategy	Public Policy	Qualitative	Quantitative	Aerospace & Defense	Automobile	Energy & Environment	IT & Communication	Service	Transportation
<i>Schenker, 1991</i>		✓			✓		✓		✓					
<i>Kochan and Rubinstein, 1997</i>		✓			✓		✓			✓				
<i>Pickett, 1997</i>	✓					✓	✓	✓			✓			
<i>Dare, 2003</i>	✓			✓			✓		✓					
<i>Grossi, 2003</i>	✓	✓	✓		✓		✓	✓	✓					
<i>Adams, 2004</i>	✓					✓	✓					✓		
<i>Mostashari and Sussman, 2004</i>	✓			✓		✓	✓							✓
<i>Mostashari, 2005</i>	✓			✓		✓	✓				✓			
<i>Catanzaro, 2006</i>	✓			✓			✓	✓	✓					
<i>Lathrop, 2006</i>	✓				✓	✓	✓		✓					
<i>McKenna, 2006</i>	✓	✓	✓		✓		✓	✓			✓			
<i>Abe, 2007</i>		✓				✓	✓							✓
<i>Cameron, 2007</i>	✓	✓		✓		✓	✓	✓	✓					
<i>Parrot, 2007</i>		✓				✓	✓	✓			✓			
<i>Donohoo, MacKenzie, McAulay, et al., 2008</i>	✓					✓	✓				✓			
<i>Hanowsky and Sussman, 2008</i>		✓				✓	✓							✓
<i>Arvind, 2009</i>		✓			✓		✓	✓				✓		
<i>Brooks, Carroll, and Beard, 2009</i>		✓		✓			✓					✓		
<i>Hashimoto, 2009</i>	✓					✓	✓	✓	✓					
<i>Sutherland, 2009</i>	✓	✓				✓	✓	✓	✓					
<i>Czaika, 2010</i>	✓			✓			✓						✓	
<i>Matty, 2010</i>		✓			✓	✓	✓	✓	✓					
<i>Alonso, 2012</i>		✓				✓	✓	✓			✓			
<i>Nam, 2012</i>		✓			✓		✓						✓	
<i>Feng, 2013 (This Thesis Itself)</i>	✓	✓	✓	✓	✓	✓	✓	✓			✓			

We realize that the breadth and depth of each research in the above table make it difficult to analyze the patterns emerging from them, and therefore tries to first capture their major characteristics from the following four aspects:

- **Theoretical Bases:**

- *System Theories*, an umbrella term referring to all the concepts, theories, and approaches related to systems, such as (1) System Representation and Modeling (see the research of Dare, 2003; Mostashari and Sussman, 2004; Mostashari, 2005; Lathrop, 2006); (2) Decision Theory and Analysis (see the research of Pickett, 1997; Adams, 2004; Catanzaro, 2006; Donohoo, MacKenzie, McAulay, et al., 2008); (3) System Dynamics (see the research of Mckenna, 2006; Hashimoto, 2009); (4) Object-Process Network (see the research of Cameron, 2007; Sutherland, 2009); (5) Design Structure Matrix (see the research of Grossi, 2003); (6) System Thinking (see the research of Czaika, 2010).
- *Stakeholder Theory*, an umbrella term referring to stakeholder-related concepts, theories, and approaches in the business and management fields, such as (1) Stakeholder Model of the Firm (see the research of Schenker, 1991; Kochan and Rubinstein, 1997; Brooks, Carroll, and Beard, 2009; Nam, 2012); (2) Stakeholder Saliency (see the research of Grossi, 2003; Abe, 2007; Hanowsky and Sussman, 2008; Matty, 2010); (3) Stakeholder Alignment (see the research of Mckenna, 2006; Parrot, 2007); (4) Stakeholder Value Network (SVN, see the research of Cameron, 2007; Sutherland, 2009; Arvind, 2009; Alonso, 2012).
- *Social Sciences*, an umbrella term referring to all the concepts, theories, and approaches in economics, sociology, political science, anthropology, psychology, etc., such as (1) Social Network Analysis (SNA, see the research of Grossi, 2003); (2) Grounded Theory (see the research of Mckenna, 2006).

- **Contributing Areas:**

- *Systems Engineering*, which means the main contribution of the corresponding research has a core of “technology”, such as (1) System Design and Architecting (see the research of Dare, 2003; Mostashari and Sussman, 2004; Mostashari, 2005; Catanzaro, 2006; Cameron, 2007; Czaika, 2010); (2) Systems Engineers’ Roles and Practices (see the research of Brooks, Carroll, and Beard, 2009).
- *Corporate Strategy*, which means the main contribution of the corresponding research has a core of “management”, such as (1) Nature of the Firm (see the research of Schenker, 1991; Kochan and Rubinstein, 1997; Nam, 2012); (2) Stakeholder Mapping (see the research of Lathrop, 2006); (3) Stakeholder Salience and Manager’s Response (see the research of Grossi, 2003; Matty, 2010); (4) Stakeholder Interaction and Alignment (see the research of McKenna, 2006); (5) Business Ecosystem (see the research of Arvind, 2009).
- *Public Policy*, which means the main contribution of the corresponding research has a core of “policy”, such as (1) Stakeholder-Informed Policy Design (see the research of Pickett, 1997; Adams, 2004; Mostashari and Sussman, 2004; Mostashari, 2005; Cameron, 2007; Donohoo, MacKenzie, McAulay, et al., 2008; Hanowsky and Sussman, 2008; Sutherland, 2009; Alonso, 2012); (2) Stakeholder-Informed Policy Implementation (see the research of Lathrop, 2006; Abe, 2007; Matty, 2010); (3) Stakeholder-Informed Policy Optimization (see the research of Parrot, 2007; Hashimoto, 2009).
- **Methodological Foci:** The methods of each research are also classified into two categories, *Qualitative* and *Quantitative*, which are self-explanatory.
- **Case Studies:** The case studies in the above research cross six industries, that is, *Aerospace and Defense, Automobile, Energy and Environment, IT and Communication, Service*, as well as *Transportation*.

Based on Table 2-2 and the above more detailed analysis, a few interesting observations can be made for the stakeholder-related research at ESD in the past twenty years:

- **Observation A:** All the 24 theses and papers applied qualitative methods, but only 11 of them applied quantitative methods at the same time.
- **Observation B:** All the 24 theses and papers included one or more case studies, which were concentrated in two industries, that is, Aerospace and Defense, as well as Energy and Environment.
- **Observation C:** The two earliest research (viz., Schenker, 1991; Kochan and Rubinstein, 1997) built their theoretical foundation in management field and also contributed to the same field; Later on, especially between 2003 and 2006, the concept of stakeholder began to interest engineering systems scholars, and the research during this period featured applying systems theories and approaches to design both physical systems and public policies; Since 2006, engineering systems scholars had paid significantly more attention on the stakeholder theory in management field, and meanwhile, their contributions also came back to the traditional field of strategic management.
- **Observation D:** Compared to system theories and management literature, the theories and approaches in social sciences, such as economics, sociology, anthropology, psychology, etc., have seen very few applications (viz., Social Network Analysis or SNA in Grossi, 2003; Grounded Theory in McKenna, 2006) in the existing stakeholder-related research at ESD.

According to a comprehensive review [Laplume, Sonpar and Litz, 2008] for 179 articles published in top management journals, stakeholder theory was initiated by Freeman in 1984, and then experienced a fast growth between 1995 and 2000, during which many nowadays most-cited stakeholder articles were published, such as Mitchell, Agle, and Wood [1997] and Rowley [1997]. Putting this result and the above Observation C together, we found that there was roughly a decade's delay between the stakeholder-related research at ESD and the frontier of stakeholder theory in the management domain. Arguably, **Value Creation and Delivery** [Freeman, Harrison, Wicks, et al., 2010; Harrison, Bosse, and Phillips, 2010; Wicks and Harrison, 2013] are currently one of the hottest topics in stakeholder theory, and our contribution to this topic helps shorten the

delay of applying the most recent development of stakeholder theory to the field of engineering systems.

More importantly, Observation D suggests that there is a pressing need to **forge a stronger connection between engineering systems and social sciences**, such as sociology—the scientific study of “human society and its origins, development, organizations, and institutions” [American Heritage Science Dictionary, 2012; Wikipedia, 2013]—in order to better “meet human needs in a complex technological world” [de Weck, Roos, and Magee, 2011]. This motivation leads to the literature review in the next section.

2.3 Approach: Network Analysis in Social Sciences

2.3.1 Relationship Types: Social vs. Economic

In social sciences, social and economic relationships are arguably two basic types of interactions between individuals or organizations. Although they are different in many ways and often studied separately by sociologists and economists, two ambitious efforts among others have been made in recent years to unify both social and economic relationships into a common framework for analysis: (1) one is the New Economic Sociology (NES), or more specifically, the Social Network Analysis (SNA), which begins with social relationships and uses the concept of “social embeddedness” to study various economic phenomena (see the work of Harrison C. White, Mark S. Granovetter, Ronald S. Burt, Paul J. DiMaggio, and Joel M. Podolny among others); (2) the other is the Social Exchange Theory (SET), which begins with economic relationships and uses the models of economic exchange to study various social situations (see the work of George C. Homans, Peter M. Blau, Richard M. Emerson, Karen S. Cook, and Peter P. Ekeh among others). These two efforts can be viewed as dual theories, echoing the distinction of “Structure vs. Process” by Van de Ven [1976], or “Structural vs. Relational” by Granovetter [1992], or “Structuralist vs. Connectionist” by Borgatti and

Foster [2003, 2009]—specifically, Social Network Analysis (SNA) corresponds to “Structure”, “Structural”, or “Structuralist”, while Social Exchange Theory (SET) corresponds to “Process”, “Relational”, or “Connectionist”—for the relationships between either individual humans or organizations [Cook and Whitmeyer, 1992].

We choose the framework from the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005] in order to gain a deep appreciation for the contents of the stakeholder relationships and avoid the separation for different types of relationships—within the framework of the Social Network Analysis (SNA), in general there are three typical approaches to study multiple types of organizational relationships [Robins and Pattison, 2006]: (1) Repeating the analysis for single-relation network multiple times and then comparing the results; (2) Using multivariate linear analysis by precluding the possible association among the networks; (3) Focusing on the number of different types of networks (viz., Multiplexity [Kapferer, 1969; Lazega and Pattison, 1999]) by stripping away the content of different networks—neither one is able to jointly analyze the interactions of multiple types of organizational relationships at the same time. In fact, some sociologists [Wasserman and Faust, 1994; Hanneman and Riddle, 2005; Robins and Pattison, 2006] have already pointed out, the research on joint analysis for multi relational networks (viz., Multiple Networks) is rather rare and will be one of the most promising future directions for the Social Network Analysis (SNA)².

Under the chosen framework of the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005], social relationships are the extension of economic

² Professor Edward Laumann introduced us his work on the “multi-strained network ties”, covering in-depth theories, useful methods, and thorough case studies which probably can be applied in the future research of Stakeholder Value Network (SVN): (1) *Networks of Collective Action: A Perspective on Community Influence Systems* [Laumann and Pappi, 1976] models three network ties (informal social, business/professional, and community affairs discussion ties) among a community elite in Germany; (2) *The Organizational State: Social Choice in National Policy Domains* [Laumann and Knoke, 1987] collects ties among hundreds of organizations active in the formation of health and energy policy in the US using multiple tie information; (3) *The Hollow Core: Private Interests in National Policy Making* [Heinz, Laumann, Nelson, and Salisbury, 1993] models conflict and alliance structures in four national policy domains – energy, health, labor, and agriculture.

relationships [Coleman, 1990; Emerson, 1976; Homans, 1961], and therefore “concepts and principles borrowed from microeconomics” [Cook, 2000, p. 687] can be applied to conduct “the economic analysis of noneconomic social situations” [Emerson, 1976, p. 336]. For example, those economic concepts and principles often include diminishing marginal utility [Blau, 1994, pp. 158-159], utility maximization [Coleman, 1994, p. 159], equilibrium and optimum [Coleman, 1990, p. 39], supply and demand, market price, imperfect competition, costs, profits, and so on³ [Coleman, 1990, pp. 719-769; Homans, 1990, pp. 77-81]. With these concepts and principles, all the human interactions, including those at the organizational level, can be reduced to a purely rational process that arises from economic theory⁴, indicating that Social Exchange Theory (SET) is “primarily a more specific variation of the rational choice model—notably, closely tied to public choice as the economic analysis of politics—rather than an autonomous theoretical paradigm” [Zafirovski, 2005, p. 5].

³ Limited by the times, Social Exchange Theory (SET) borrows the rational choice model from neoclassical economics as its economic foundation and still adheres to the “holy trinity” of “rationality, selfishness, and equilibrium” [Colander, Holt, and Rosser, 2004, p. 485]. Therefore, these features should also be interpreted as assumptions or limitations of the Stakeholder Value Network (SVN) approach. However, although having these limitations, the main purpose of this dissertation is not to calculate the accurate amount of value exchanged through stakeholder relationships, but to understand and demonstrate the impacts of indirect stakeholder relationships. Moreover, once the basic framework of the SVN approach is built up, it will always be possible to revisit these limitations and make the model better, as briefly discussed in the next footnote.

⁴ The latest developments in economic theory bring tremendous opportunities to improve the rational choice model, which has been taken as the economic foundation of Social Exchange Theory (SET) and therefore Stakeholder Value Network (SVN): (1) First, *Behavioral Economics* studies the effects of cognitive and emotional elements in human’s economic decisions as well as the consequences for market exchange and resource allocation. A few key concepts in this new branch of economics, such as bounded rationality [Simon, 1972, 1997], information impactedness [Williamson, 1975], intertemporal choice [Loewenstein and Prelec, 1992; Berns, Laibson, and Loewenstein, 2007], prospect theory [Kahneman and Tversky, 1979; Tversky and Kahneman, 1992], and evolutionary game theory [Weibull, 1997] among others, can be introduced to the future SET and SVN research; (2) Second, *Complexity Economics* studies the economic dynamics with computer simulation and challenges the traditional equilibrium assumption for economic systems. A few important ideas [Arthur, Durlauf, and Lane, 1997] in this new branch of economics, such as dispersed interaction, no global controller, cross-cutting hierarchical organization, ongoing adaptation, novelty niches, and out-of-equilibrium dynamics among others, can also be introduced to the future SET and SVN research.

Astute readers may be interested in the question whether it is appropriate to extend the economic and sociological theories developed on the individual level, including the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005], to the organizational level. We do assume that the same network model of actors can be used for both individual humans and organizations, but meanwhile, we would also like to assert that “this assumption is widespread among network analysts whose actors are organizations (e.g. Laumann et al 1985, Mizruchi 1989, 1990ab), and widespread among exchange theorists (e.g. Emerson 1972b, Markovsky et al 1988) and indeed some other theorists in sociology (e.g. Berger et al 1989)” [Cook and Whitmeyer, 1992, p. 117].

At this stage, it is important to recall one of the three basic problems studied by stakeholder scholars in the management domain (see Section 2.2.1), that is, the “Problem of Value Creation and Trade” [Freeman, Harrison, Wicks, et al., 2010, pp. 4-5 and p. 29]. In order to be better equipped to tackle with this specific problem, one must resort to economic concepts and principles, which also justify our motivation to choose the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005] as the theoretical cornerstone for the Stakeholder Value Network (SVN). In fact, the concepts and principles from economics, such as utility, reciprocity, competition, and so on, have been recently discussed a lot by stakeholder scholars [Harrison, Bosse, and Phillips, 2010; Wicks and Harrison, 2013].

2.3.2 Exchange Patterns: Restricted vs. Generalized

Once unifying both social and economic relationships into value exchanges under the framework of the Social Exchange Theory (SET), sociologists (with the early contribution of anthropologists) [Emerson, 1976; Homans, 1958; Levi-Strauss, 1949; Malinowski, 1922] discover two generic patterns for the exchange of values, which can be either monetary or nonmonetary, in human’s economic and social life: (1) “Restricted Exchange”, the dyadic reciprocal relationships between two parties in the exchange situation that may be represented diagrammatically as “ $A \Leftrightarrow B$ ”; and (2) “Generalized Exchange”, the univocal reciprocal relationships among at least three parties in the

exchange situation that may be represented diagrammatically as “ $A \Rightarrow B \Rightarrow C \Rightarrow A$ ”. Different from Restricted Exchange, Generalized Exchange neither requires immediate reciprocation nor creates a direct obligation to a specific benefactor, and therefore heavily relies on the social contracts mediated by the nonmarket environment, instead of the economic contracts mediated by the market environment.

However, the logic linking the types of stakeholder relationships (viz., economic and social relationships) with the patterns for stakeholders to exchange values (viz., Restricted and Generalized Exchanges) has not been fully understood. As such, we argue that economic relationships mainly exist in the form of Restricted Exchange, while social relationships mainly exist in the form of Generalized Exchange, for two major reasons:

- First, on the individual and micro- levels, economic relationships often feature specified economic contracts bonded by laws as well as legal obligations and mainly aim for the extrinsic reward (viz., materials gains), and therefore are usually “one-shot transactions”⁵ [Cook, 2000, p. 687] mediated in the market environment. By contrast, social relationships often feature unspecified social contracts bonded by trust as well as social norms and mainly aim for both the intrinsic and extrinsic rewards, and therefore are usually “enduring long-term relations” [Cook, 2000, p. 687] mediated in the nonmarket environment. Recalling the difference between Restricted and Generalized Exchanges, it is not difficult to find the connection between economic relationships and Restricted Exchange through the market environment, as well as the connection between social relationships and Generalized Exchange through the nonmarket environment.
- Second, on the meso- and macro- levels, social relationships can also be conceived as the interchanges between various social systems. Under such an interchange, Generalized Exchange will be the dominant pattern through

⁵ As pointed out by Professor Donald Lessard, for large engineering projects, it is quite normal for two parties to have a long run relational contract based on (the shadow of) future dyadic relationship that is not supported by a generalized exchange—therefore the statement of equating restricted exchanges as one-shot transactions may not be accurate.

connecting different types of social relationships into one path or cycle. As argued by Zafirovski [2005, p. 24], “each social system, e.g. economic, political, communal, and cultural, can be as Pareto, Parsons and other suggest, assumed to exchange ‘inputs’ and ‘outputs’ with the other systems. Notably, these exchanges between social systems represent multilateral or collective rather than bilateral or individual exchanges.”

Further, after establishing the link between relationship types and exchange patterns, we argue that Generalized Exchange is the primary pattern of value exchanges when social relationships prevail⁶. Note that this argument attempts to improve the early behaviorist-rational choice version of the Social Exchange Theory (SET, mainly by Homans and Blau among others), which treats the Restricted Exchange as primary because of the “psychological reinforcement”, and the significance of Generalized Exchange can be interpreted from the following two aspects:

- From a normative perspective, one basic assumption for the Social Exchange Theory (SET) is to transform *homo economicus* (viz., economic man) “from a rational egoist (Hechter and Kanazawa, 1997) or an asocial subject (‘rational fool’ as termed by Sen, 1977) to a new actor holding not only utilitarian or hedonistic but also altruistic or social values”⁷ [Zafirovski, 2005, p. 3]. This assumption is consistent with the focus of the (normative) Stakeholder Theory on “the identification of moral or philosophical guidelines for the operation and management of corporations” [Donaldson and Preston, 1995, p. 71]. For these social relationships bonded by trust and social norms as well as mediated in the nonmarket environment, as discussed previously, mainly exist in the form of Generalized Exchange.

⁶ Professor Donald Lessard suggested, the more important distinction between restricted and generalized exchanges relies on whether the exchanges involve one type of value, e.g. money, or various (objects of value) that are not commensurate in general terms.

⁷ Some criticism of Social Exchange Theory (SET) argues it may be self-contradictory to include both utilitarian/hedonistic and altruistic/social values, while still selecting the rational choice model from neoclassical economics as the mathematical foundation of SET.

- From an instrumental perspective, other scholars emphasize the existence of Generalized Exchange in organizations' strategic behavior, such as Olson's theory [1965] on the logic for collective action, as well as Shah and Levine's examples [2003] for the Generalized Exchange among large and often heterogeneous organizations. Baron's Nonmarket Strategy Map [1995, p. 59, Figure 4] can also be a source of unconscious support for the existence of Generalized Exchange in the strategic behavior of modern organizations. In addition, as observed in the decisions of modern firms, Generalized Exchange is a widely practiced strategy, especially when it is difficult for a focal organization to engage its stakeholders directly.

2.3.3 Strategic Implications: Importance, Power, and Centrality

Based on the above literature and discussion on the relationship types and exchange patterns, we now turn to a more fundamental question, that is, how should the implications of these networks be interpreted from the perspective of strategic management? As argued by Smith, Mitchell, and Summer [1985] and Cameron, Crawley, Feng, and Lin [2011, p. 37], "Managing, at a simple level, is a process of setting priorities, particularly among uncertain outcomes, and then observing how outcomes proceed according to those priorities"⁸. More specifically, for the value creation and trade among stakeholders, Freeman, Harrison, Wicks, et al. [2010, p. 24] also proposed to differentiate the "primary stakeholders" from the "secondary stakeholders"—although such a proposal is more centered on an instrumental perspective than a normative one, it is not practical for firms and managers to evenly allocate their limited resources in reality to every stakeholder. Therefore when interpreting the strategic implications of stakeholder networks, we put the first priority on understanding the "Importance" of different stakeholders. Note that the word of "Importance" here can be taken as a layman's expression for the "Salience" defined by Mitchell, Agle, and Wood [1997].

⁸ As pointed out by Professor Donald Lessard, this is an engineering perspective for management. In fact, managing also involves conversation, persuasion, and intervention to cause individuals and organizations to move in the direction of priorities.

It would be beneficial to track down the economic and sociological roots for the word “Importance”—we find that “Power” (see the work of Karl Marx, Max Weber, Georg Simmel, Pierre Bourdieu, Jürgen Habermas, and Michel Foucault among others) and “Centrality” (see the work of Harrison C. White, Mark S. Granovetter, Ronald S. Burt, Paul J. DiMaggio, and Joel M. Podolny among others) are two closest concepts in the vocabulary of economists and sociologists.

In traditional economics, “Power” is a secondary and derivative phenomenon determined by market exchange, and more specifically, rational choice theory points out that “power concept is a generalization of the wealth concept in economic theory” [Fararo, 2001, p. 266]. As “the economic analysis of noneconomic social situations” [Emerson, 1976, p. 336], Social Exchange Theory (SET), which provides the theoretical foundation for this dissertation, also treats exchange as a more fundamental phenomenon than power [Cook, 1990, pp. 115-116], by assuming that power emerges and evolves in a complex structure of exchanges of resources—“since these exchanges are governed by the objective structure of alternatives, the latter determines power (and dependence) and gives it the character of a structural variable residing within exchange networks” [Zafirovski, 2005, p. 7]. These arguments further validate the opportunity to improve the current theory on Stakeholder Saliency [Agle, Mitchell, and Sonnenfeld, 1999; Mitchell, Agle, and Wood, 1997], which directly associates power with stakeholders without examining the multiple and networked relationships between stakeholders (see Section 2.2.2.1).

By contrast, in the structural style network analysis (viz., Social Network Analysis or SNA), “Centrality” generally means the “network position-conferred advantage” [Cook and Whitmeyer, 1992, p. 120]. For example, Table 2-3 lists three common types of centrality in the Social Network Analysis (SNA) [Wasserman and Faust, 1994] and their implications for the stakeholder network.

Table 2-3: Three Types of Centrality in the Social Network Analysis (SNA)

	Definition	Equation	Implication
Degree Centrality	The number of ties the reference stakeholder has with other stakeholders	$C_D(n_i) = d(n_i) = \sum_j x_{ij} = \sum_i x_{ji}$	Stakeholder Importance measured by the access to alternative resources
Closeness Centrality	The sum of the lengths of the shortest geodesic paths from the reference stakeholder to all other stakeholders	$C_C(n_i) = \left[\sum_{j=1}^g d(n_i, n_j) \right]^{-1}$	Stakeholder Importance measured by the communication efficiency to other stakeholders
Betweenness Centrality	The frequency with which the reference stakeholder falls on the geodesic paths between pairs of other stakeholders	$C_B(n_i) = \sum_{j < k} \frac{g_{jk}(n_i)}{g_{jk}}$	Stakeholder Importance measured by the control over other stakeholders

In some variants of the Social Exchange Theory (SET), “Power” exhibits a direct correlation to “Centrality” [Bonacich, 1987], with exceptions where central positions do not necessarily imply superior power [Cook, Emerson, Gillmore, and Yamagishi, 1983]. Meanwhile, since the work of Emerson [1972, 1976], Social Exchange Theory (SET) has increasingly considered network structure explicitly, which leads to the development of “Exchange Networks” or “Network Exchange Theory” [Cook and Emerson, 1978; Walker, Thye, Simpson, et al. 2000; Yamagishi, Gillmore, and Cook, 1988; Yamagishi and Cook, 1990]. However, two basic differences still exist when applying these two approaches to measure the “Power” or “Centrality” of network actors: (1) different treatment of the ties between network actors—Social Exchange Theory (SET) stresses the exchange aspects of all ties, while Social Network Analysis (SNA) tends to be more catholic about the nature of the ties [Cook and Whitmeyer, 1992]; (2) different focus on the basic units of network structure—Social Exchange Theory (SET) mainly studies the dyadic ties (viz., restricted exchanges), because of the “psychological reinforcement” discussed before, while Social Network Analysis (SNA) includes much more patterns of network structure, although the network itself usually consists of only one type of relationship [Cook, Cheshire, and Gerbasi, 2006].

2.3.4 Research Opportunities for Network Analysis

Figure 2-8 visualizes the research gap identified from the above literature review: the horizontal axis is divided into two areas by relationship type (see Section 2.3.1), while the vertical axis is divided into two areas by exchange pattern (see Section 2.3.2). Note that for the relationship types, “Single” means only one type of relationship is allowed at each time of network analysis, and “Multiple” means multiple types of relationships (viz., both social and economic) can be studied at the same time. In addition, for the exchange patterns, “Restricted” and “Generalized” focus on the corresponding network structure (viz., dyads for “Restricted” and cycles for “Generalized”), rather than the exchange contents of that structure.

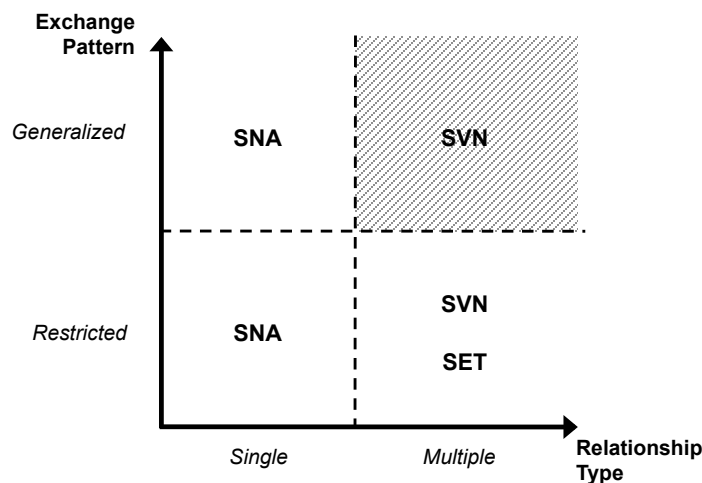


Figure 2-8: Research Gap for the Network Analysis in Social Sciences

Putting these two axes together, four research subareas emerge for the network analysis in social sciences (see Figure 2-8): (1) Social Network Analysis (SNA) covers two subareas by studying single-relation networks without restriction on network structure; (2) Social Exchange Theory (SET) only covers one subarea by studying multi-relation networks with restriction on network structure; (3) Stakeholder Value Network (SVN) developed in this dissertation aims to cover two subareas for multi-relation networks consisting of both restricted and generalized exchanges; (4) The shadowed subarea, “Multiple” and “Generalized”, indicates the gap for current network research in social

sciences, or the potential new contribution of the Stakeholder Value Network (SVN), in terms of understanding the impacts of indirect and multi-type stakeholder relationships on the long-term success of large engineering projects.

Once the research directions for the Stakeholder Value Network (SVN) are identified, two closely-related challenges will immediately follow: (1) How to define network measurements and construct network statistics, which are similar to the “Power” in Social Exchange Theory (SET) or the “Centrality” in Social Network Analysis (SNA), to interpret the “Importance” of stakeholders in the Stakeholder Value Network (SVN)? (2) How to build a computationally efficient and cost-effective modeling platform for the analysis of Stakeholder Value Network (SVN)? These two pressing challenges bring more promising opportunities for this dissertation.

2.4 Integrating Domains with Approach: Stakeholder Value Network

2.4.1 Stakeholder Value Network: Definition and Assumptions

As discussed in Section 2.2.2, Rowley [1997] proposed to apply the network analysis to understand stakeholder influence. Meanwhile, Mahon, Heugens, and Lamertz [2004] as well as Lucea [2007] also proposed to integrate stakeholders with strategic issues through the network approach. However, limited by the then available choices of network analytic methodologies in the social sciences, all of these proposals only considered Social Network Analysis (SNA), which views stakeholder relationships as empty social ties (without issue content) and studies the impacts of network structures on stakeholders’ behavior. As discussed previously, the strength of Social Network Analysis (SNA) lies in providing a way to measure the structural properties of the whole network (viz., density, etc.) and the structural positions of individual stakeholders (viz., degree-, closeness-, and betweenness- centralities, etc.), with a rigorous basis in graph theory. However, the weakness of this approach lies in the separation for different types of stakeholder

relationships—only the same type of relationships will be put into one network and all these structural measurements are defined for such kind of single-relation networks.

In order to overcome this weakness of such a purely structural view, this dissertation and its forerunners [Cameron, 2007; Sutherland, 2009] have developed over years a new network approach, viz., the Stakeholder Value Network (SVN), which views multiple types of stakeholder relationships (both social and economic) as value exchanges (both restricted and generalized) and then studies the strategic implications of the exchanged value flowing through the stakeholder network, so that the influence from value exchange and network structure can be both captured at the same time and in one unified framework.

Before the construction of methodological framework, we first formally define the **Stakeholder Value Network (SVN)** as “**a multi-relational network consisting of a focal organization, the focal organization’s stakeholders, and the tangible and intangible value exchanges between the focal organization and its stakeholders, as well as between the stakeholders themselves**”: (1) the *focal organization* can be a company, a project within a company, a joint venture between companies, a government agency, a non-government organization (NGO), or any other type of organization; (2) a *stakeholder* for the focal organization is “any group or individual who can affect or is affected by the achievement of the organization’s objectives” [Freeman, 1984, p. 46], although this definition is too broad to be used directly in practice—more guidance for stakeholder identification will be discussed in Chapter 3; (3) *value exchanges* are the processes by which the specific needs of the focal organization and/or stakeholders are satisfied at a desirable cost [Cook, 1990; Crawley, 2009]. In this dissertation, the focal organization generally refers to a large engineering project conducted by companies or governments; stakeholders are usually organizations instead of individuals or social groups; and tangible value is often associated with the economic or monetary exchanges for goods/service and financial resources, while intangible value is often associated with the social or nonmonetary exchanges for political resources (political support, regulatory approval, etc.) and information (technical know-how, process knowledge, etc.).

On the basis of literature review, we firmly ground our theoretical foundation in Social Exchange Theory (SET) [Emerson, 1976; Homans, 1958; Lévi-Strauss, 1949; Malinowski, 1922], and correspondingly, three key assumptions are made as below for the Stakeholder Value Network (SVN) analysis:

- **Relationship Types:** Social exchanges are the extension of economic exchanges [Coleman, 1990; Emerson, 1976; Homans, 1961], and therefore monetary and nonmonetary relationships between stakeholders can be analyzed in a common framework, with the use of subjective utility judgments as well as comparison of alternatives;
- **Exchange Patterns:** Multilateral and indirect value exchanges exist widely in the strategic behavior of modern organizations [Olson, 1965; Shah and Levine, 2003; Westphal and Zajac, 1997], and therefore generalized exchanges can be taken as the basis to understand the impacts of indirect relationships between stakeholders;
- **Strategic Implications:** Stakeholder power is the outcome of both exchange relations and network positions [Blau, 1964; Emerson, 1972; Molm, 1990], and therefore network statistics can be constructed from the sample space of generalized exchanges to measure the importance of stakeholders as well as other metrics of interest.

Note that “generalized exchanges” in the above assumptions also include “restricted exchanges” (see Figure 2-8), which for simplicity are treated as a special case of generalized exchanges (viz., between two, not three or more, stakeholders) by this dissertation. In addition, to help understand the logical consistency between theoretical foundation and methodological framework in this dissertation, these three assumptions can be linked back to three sections of literature review (2.3.1, 2.3.2, and 2.3.3, respectively), and meanwhile, they can also be mapped forward to three key steps in the methodological framework of the Stakeholder Value Network (SVN) analysis (see Chapter 3).

2.4.2 Basic Units of Network Analysis: Saliency, Relationships, and Issues

After reviewing the relevant literature across engineering, management, and social science as well as establishing the theoretical foundation with key assumptions for the Stakeholder Value Network (SVN) analysis, this last section discusses the basic units of network analysis to gain a deeper appreciation for the correlations between Stakeholder Theory, Strategic Issue Management, and the Stakeholder Value Network (SVN) analysis (see Figure 2-1).

As the gurus for the network analysis in social sciences during the past century, Laumann, Marsden, and Prensky [1983] once pointed out that “nodal attributes”, “relations”, and “participation in specified events or activities” are three foci to define the boundary of a network, and then they further developed a typology of eight strategies for boundary specification (see Table 2-4). Note that they also distinguished between “nominalist” and “realist” views of social phenomena—the former means “an analyst self-consciously imposes a conceptual framework constructed to serve his own analytic purposes” [Laumann, Marsden, and Prensky, 1983, p. 21], while the latter means “the network is treated as a social fact only in that it is consciously experienced as such by the actors composing it” [Laumann, Marsden, and Prensky, 1983, pp. 20-21]—obviously the Stakeholder Value Network (SVN) analysis is closer to the “nominalist” view than the “realist” one.

From Table 2-4, we further infer that “node attributes”, “relations”, and “participation in events or activities” are three types of basic units in network analysis and close to the definitions of stakeholder saliency, stakeholder relationships, and strategic issues, respectively. In addition, as argued by Laumann, Marsden, and Prensky [1983], “node attributes”, “relations”, and “participation in events or activities” can actually complement each other and help specify the appropriate network boundaries (see Strategy VIII in Table 2-4). Based on this insight, although by definition stakeholder relationships constitute the units of analysis for the Stakeholder Value Network (SVN),

we will also explore the synergy between stakeholder salience, stakeholder relationships, and strategic issues, in terms of both boundary specification as well as the interpretation for strategic implications.

Table 2-4: A Typology of Boundary Specification Strategies for Delimiting Actors within a Network
 [Adapted from Laumann, Marsden, and Prensky, 1983, p. 25]

<i>Metatheoretical Perspective</i>	<i>Definitional Focus for Delimitation</i>			
	<i>Attributes of Nodes</i>	<i>Relation</i>	<i>Participation in Event or Activity</i>	<i>Multiple Foci</i>
<i>Realist</i>	<p><i>I</i></p> <p>Corporate group [Weber, 1947] Bank wiring room [Roethlisberger and Dickson, 1939] Monastery [Sampson, 1969] High school [Coleman, 1961; Fararo and Sunshine, 1964] Norwegian Island Parish [Barnes, 1954] Cell room of Electrozinc Plant [Kapferer, 1969] School classroom [Davis, 1970]</p>	<p><i>III</i></p> <p>Primary group, clique [Cooley, 1909]</p>	<p><i>V</i></p> <p>Participants in a community controversy [Dahl, 1961] Participants in common social events [Homans, 1950] Street corner society [Whyte, 1955]</p>	<p><i>VII</i></p> <p><i>Klasse fur sich</i> [Marx] Ethnic community [Barth, 1975; Laumann, 1973; Yancey et al., 1976]</p>
<i>Nominalist</i>	<p><i>II</i></p> <p><i>Klasse an sich</i> [Marx] Doctors in small cities [Coleman et al., 1966] Formal organizations in small city [Galaskiewicz, 1979] American business elite [Useem, 1979] Community influential [Laumann and Pappi, 1973, 1976]</p>	<p><i>IV</i></p> <p>Small world problem [Travers and Milgram, 1969; Erickson, 1978]</p>	<p><i>VI</i></p> <p>Invisible college [Crane, 1972; Burt, 1978; Breiger, 1976]</p>	<p><i>VIII</i></p> <p>Supporters of psycho-therapy [Kadushin, 1966] National elite circles [Moore, 1979]</p>

2.5 Chapter Summary

At the end of this chapter, it is worthwhile to recapitulate all the research opportunities identified from the literature review, as well as to map them to specific chapters and

sections in this dissertation (see Table 2-5). In this way, scholars and practitioners with different disciplinary background of engineering, management and social sciences can more easily grasp the whole structure of this dissertation and even choose to first read the chapters and sections interesting them the most.

Table 2-5: Mapping Research Opportunities to Dissertation Chapters and Sections

Discipline and Field	Research Opportunity	Dissertation Chapter / Section
<i>Strategic Management and Stakeholder Theory</i>	Stakeholder Saliency	Section 3.2; Chapter 4; Section 5.3; Chapter 6
	Stakeholder Network Model	Section 3.2; Section 5.3
	Stakeholders and Strategic Issues	Section 3.3; Section 4.4
<i>Engineering Systems and Large Engineering Projects</i>	Multiple Relations as Value Exchanges	Section 3.2; Section 7.3
	Generalized Exchanges and Impacts of Indirect Stakeholder Relationships	Section 3.4; Section 4.3
	Stakeholder-Oriented System Architecting	Appendix I
<i>Social Sciences and Network Analysis</i>	Common Framework Unifying Both Social and Economic Relationships	Section 3.2; Section 5.3
	Connection between Relationship Types and Exchange Patterns	Section 4.3
	Saliency/Importance/Power/Centrality in Exchange Networks with Weak Ties	Section 3.2; Section 5.3
	Modeling Platform and Analytical Tool	Section 5.2

As shown in Figure 1-1, the next chapter accounts for the first stage of the methodological development for the Stakeholder Value Network (SVN) analysis, with a focus on interpreting the network implications from the perspective of a focal organization, which is often a large engineering project in the context of this dissertation.

CHAPTER 3. METHODOLOGY DEVELOPMENT I: SVN FOR A FOCAL ORGANIZATION

“... little is known in the way of formulating strategies for utilizing such networks in a positive and proactive fashion. Little is known, prescriptively, about what range of alternatives is open to managers who want to utilize such an indirect approach to dealing with stakeholders.”

— Freeman [1984, p. 58]

3.1 Chapter Introduction

This chapter lays out the methodological foundation for analyzing the SVN from the viewpoint of a focal organization. According to the definition of SVN in Chapter 2, SVN analysis is a method viewing multiple stakeholder relationships as value exchanges and studying the strategic implications of different types of value flowing throughout the stakeholder network. By virtue of SVN analysis, the focal organization should be able to understand the impacts of both direct and indirect relationships between stakeholders on the long-term success of achieving its objectives, as well as apply such an understanding to formulate stakeholder management strategies in a positive way and with reduced complexity. Moreover, this method builds a common platform for different departments within the focal organization to communicate the important information about stakeholders.

There are three specific goals that the SVN analysis must accomplish:

- **Data Collection:** To develop a comprehensive understanding of the stakeholders of a focal organization, By articulating the roles, objectives, and needs of each stakeholder, Using information collected from documents and interviews;
- **Qualitative Model:** To capture both direct and indirect relationships among all the stakeholders, By mapping their specific needs as “value flows” within a network, Using information garnered from the articulation of stakeholder needs;
- **Quantitative Model:** To identify the critical “value paths”, the high-leverage outputs, as well as the most important stakeholders and value flows for the focal organization, By conducting a rigorous network analysis, Using the network measurements defined in and the network statistics calculated from this analysis.

In particular, a value flow is defined as the output of one stakeholder, and at the same time, the input of another; and a value path is defined as a string of value flows connecting a group of stakeholders. Following the above goals, the essence of the SVN analysis can be summarized in a **Four-Step Modeling Framework**, which is first discussed in this chapter, with the illustration of a running example for a multinational energy project. And then, two important extensions are made for this framework: First, an **Integration of Stakeholders and Issues** is proposed to reveal additional insights into the balance of stakeholder relationships and reduce the dimensionality of the network model; Second, a **Utility Model for Generalized Exchanges** is established to improve the calculation for the scores of value paths in the stakeholder network. In the next chapter, the whole framework and its two extensions are applied to the SVN analysis for a real case of large engineering project: “Project Phoenix”.

3.2 Basics: Four-Step Modeling Framework

Initiated by Cameron [2007] and developed by Sutherland [2009] as well as this dissertation, the methodological framework of the SVN analysis has grown mature gradually and mainly consists of the following four steps:

- **Mapping:** At the beginning, the focal organization should be defined and its stakeholders should be identified. Meanwhile, their roles, objectives, and specific needs will also be extracted from documents and interviews. Based on this information, a qualitative model of the SVN can be built, in the format of stakeholder maps, through mapping the specific needs of each stakeholder as value flows.
- **Quantifying:** Once the stakeholder maps are obtained, the next step is to score value flows with the perceived utility of the recipient stakeholder and define the propagation rule of value flows in the stakeholder network to calculate the score of a value path.
- **Searching:** Based on the quantified value flows and the value propagation rule, a quantitative model of the SVN can be built, to search for all the value paths beginning from and ending with the focal organization as the sample space for a rigorous network analysis.
- **Analyzing:** Once the quantitative model finds all the value paths for the focal organization, the last step is to define network measurements and construct network statistics in order to study the strategic implications of the SVN for that focal organization.

For a better understanding, this framework can be visualized in Figure 3-1, using the Object-Process Diagram (OPD) [Dori, 2002], where the rectangle represents an object (i.e., a noun), the oval represents a process (i.e., a verb), and the line ending with a hollow cycle represents an “instrument” link (i.e., process requires object). In this figure, the inputs and outputs as well as the corresponding techniques of each step in the SVN analysis are clearly shown. Note that these four steps can be implemented in an iterative manner (see the dotted oval and arrows, representing a possible “fifth” step), when more information for the SVN becomes available, or the situation of previous analysis changes.

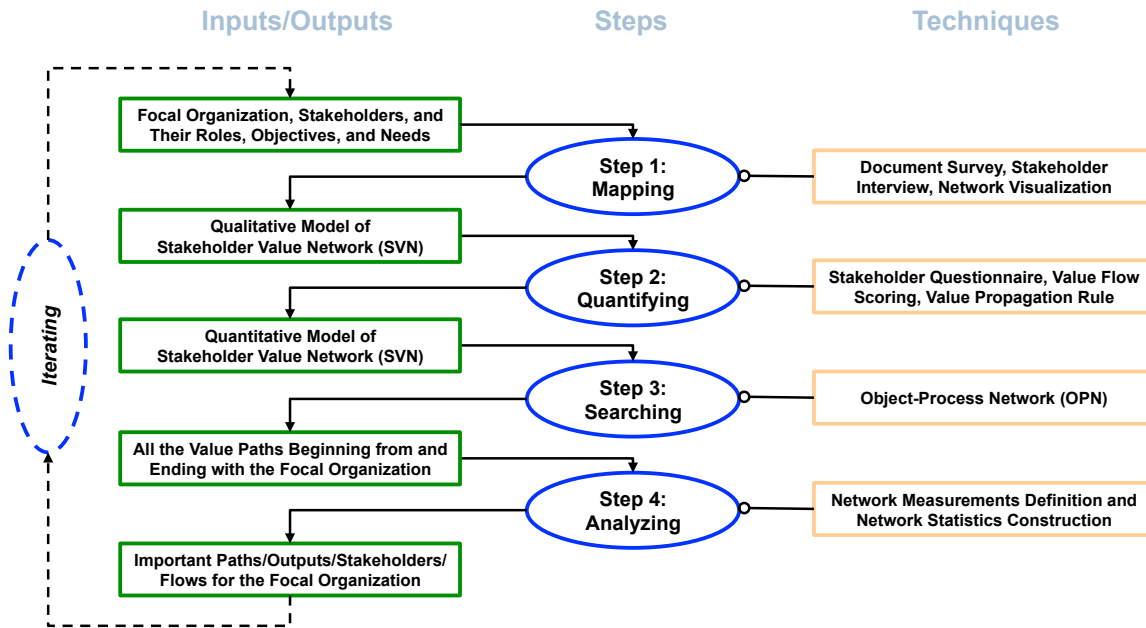


Figure 3-1: Four-Step Modeling Framework for the SVN Analysis

This four-step modeling framework is quite general and hence theoretically, is suitable for the use in any circumstance involving complex interactions between multiple stakeholders. In this section, we illustrate the SVN framework with an application to a multinational energy project, RuSakOil.

RuSakOil is based on a multi-year and multi-billion dollar offshore oil exploration and production (E&P) project invested by an international energy giant. On one hand, this project has been simplified enough for the purpose of demonstration; On the other hand, it still remains representative for many multinational investments in the energy industry.

Here is a brief introduction to this example:

The Enterprise is a large multinational with expertise in the exploration and production of oil & gas and has recently secured the rights to a significant reservoir in a foreign country by creating a multi-billion joint venture (i.e., Project) with a local firm (i.e., Host-Country Corporation). While the Project will be technically challenging, there are early

indications that the complexity of the external relations, in both market and nonmarket environment, will pose the most significant risk to the successful completion of the Project. Specifically, from the market side, the Host-Country Corporation tries to gain more revenue sharing and increase the transfer of technology; from the nonmarket side, the Host-Country Government lacks of the credibility, and the Local Community wants to create more jobs before giving its regulatory approval for the environmental compliance of the Project.

Next, a step-by-step SVN analysis is conducted for the RuSakOil, under the guidance of the framework shown in Figure 3-1. Specifically, we put the focus of each step on the elaboration for its general process and techniques, which can be taken as a stand-alone manual, rather than the narrow discussion of this specific example.

3.2.1 Step One: Mapping

Mapping is the first step of the SVN analysis. Its specific goal is to develop a qualitative model of the SVN: articulating the roles, objectives, and specific needs of each stakeholder and then mapping their specific needs as value flows. Such a qualitative model, in the format of stakeholder maps, provides a vivid and comprehensive description of the stakeholders of a focal organization as well as the direct and indirect relationships between them.

First of all, the focal organization, which is both the starting point and the final destination of the whole SVN analysis, should be unambiguously defined. In the case of RuSakOil, the focal organization can be either the Enterprise or the Project, depending on which one is of the major research interest as well as where the organizational boundaries are set. For simplicity, the Project is chosen as the focal organization here and will also

be treated as an entity independent from the Enterprise⁹, although for a joint venture, the organizational overlap between the Project and the Enterprise is unavoidable.

After choosing the focal organization, there are still two challenges in the first step: stakeholder identification and value flow definition.

3.2.1.1 Stakeholder Identification

Identifying the stakeholders of the focal organization is one of the most important components in the whole SVN analysis, not only because missing a key stakeholder could jeopardize the chance for the focal organization to successfully achieve its objectives in the long run, but also because all the value flows in the SVN are derived from the stakeholders and the inaccuracy in stakeholder identification will ripple through the definition of value flows as well as the remaining process of the SVN analysis.

However, stakeholder identification is not an easy task, in consideration of the fact that the community lacks a specific and unambiguous definition for “stakeholder” [Mitchell, Agle, and Wood, 1997]. Freeman’s now-classic definition seems too broad: “*A stakeholder in an organization is (by definition) any group or individual who can affect or is affected by the achievement of the organization’s objectives*” [1984, p. 46]. In this dissertation, three approaches are suggested together as a practical guidance for stakeholder identification.

First, the MIT System Architecture Group [Crawley, 2009; Sutherland, 2009] defined stakeholders more specifically as those who: (1) have a direct or indirect affect on the focal organization’s activities, or (2) receive direct or indirect benefits from the focal organization’s activities, or (3) possess a significant, legitimate interest in the focal organization’s activities. With this definition, the types of stakeholders for a project (i.e., the focal organization) generally include:

⁹ Otherwise many value flows from the Enterprise and Host-Country Corporation to the Project will be eliminated from the SVN model.

- **“Stake” Holders:** Those who have a direct stake in the project;
- **Beneficiaries:** Those who derive benefits from the project;
- **Users:** The ultimate consumers or users of the project’s outputs;
- **Agents:** Those who act on behalf of other stakeholders in the model;
- **Institutions:** Official bodies or organizations¹⁰ that directly impact the project;
- **Interests**¹¹: Those with a significant, legitimate interest in the project’s outputs, who may not be considered a direct stakeholder in the traditional sense;
- **Project:** Relatively, the focal organization itself is also a stakeholder in the eyes of other stakeholders.

Particularly, for the RuSakOil described before, “stake” holders can be Enterprise, Host-Country Corporation, Investors, and Suppliers; beneficiaries can be Local Community; users can be Consumers; institutions can be Host-Country Government; and interests can be NGOs¹² or other social movements and groups.

Second, from the perspective of project management, Calvert [1995], Cleland [1998], and Winch [2004] proposed a classification for the stakeholders of a project (see Table 3-1), which is also helpful for stakeholder identification:

¹⁰ In the literature of social sciences (<http://plato.stanford.edu/archives/fall2012/entries/social-institutions/>), “institutions” are often organizations [Scott, 2001], or systems of organizations (e.g., capitalism). However, some institutions (e.g., English) are not organizations, or systems of organizations, and do not require organizations. A typical definition of “institutions” is [Turner 1997, p. 6]: “A complex of positions, roles, norms and values lodged in particular types of social structures and organizing relatively stable patterns of human activity with respect to fundamental problems in producing life-sustaining resources, in reproducing individuals, and in sustaining viable societal structures within a given environment.” Or as Harre [1979, p. 98] defined: “An interlocking double-structure of persons-as-role-holders or office-bearers and the like, and of social practices involving both expressive and practical aims and outcomes.”

¹¹ Note that we define “Institutions” and “Interests” as stakeholders, which are different from Baron’s original definitions [1995] as the characteristics of stakeholders.

¹² Nowadays there are still lots of debates about the legitimacy of NGOs’ interests. For example, who gives responsibilities to NGOs and how do NGOs obtain the representation of citizens and civil society [Edwards and Hulme, 2002]; whether or not the funding sources for NGOs are independent [Edwards and Hulme, 1996]; whether or not NGOs sufficiently represent the needs of developing countries [Lindenberg and Bryant, 2001]; among others.

- **Internal Stakeholders:** Those who have a contractual relationship with the project or a subcontract from another internal stakeholder. Internal stakeholders can be further broken down to those on the Demand side and those on the Supply side for the project.
- **External Stakeholders:** Those who may have little choice about whether the project goes ahead and may be positive, negative, or indifferent about the project. External stakeholders can be further divided into Private and Public actors.

However, there are a few inaccurate places¹³ in the above definitions from our viewpoint, and we suggest to rename the “internal stakeholders” and “external stakeholders” as “market stakeholders” and “nonmarket stakeholders” [Baron, 1995], respectively: The internal stakeholders usually exist in the market environment, which includes those interactions between the focal organization and other parties that are intermediated by markets; While the external stakeholder usually exist in the nonmarket environment, which consists of the social, political, and legal arrangements that structure the focal organization’s interactions outside of, and in conjunction with, markets.

Table 3-1: Some Project Stakeholders [Winch, 2004, p. 323]

Internal Stakeholders		External Stakeholders	
<i>Demand Side</i>	<i>Supply Side</i>	<i>Private</i>	<i>Public</i>
Client	Consulting engineers	Local residents	Regulatory agencies
Sponsor	Principal contractors	Local landowners	Local government
Financiers	Trade contractors	Environmentalists	National government
Client’s employees	Materials suppliers	Conservationists	
Client’s customers	Employees of the above	Archaeologists	
Client’s tenants			
Client’s suppliers			

¹³ As pointed out by Professors Jeffrey Harrison and Donald Lessard, Calvert, Cleland, and Winch’s descriptions of “internal stakeholders” and “external stakeholders” are not accurate—typically internal and external stakeholders are distinguished by the organizational boundaries of firms or projects. In addition, for the “external stakeholders”, some of them are quite powerful and can even block the whole project, and therefore the statement of “who may have little choice” is also inaccurate.

Specifically, for the RuSakOil, Enterprise, Host-Country Corporation, Investors, and Consumers can be the internal stakeholders identified from the demand side; Suppliers can be the internal stakeholders identified from the supply side; NGO can be the external stakeholders identified from the private sector; and Local Community and Host-Country Government can be the external stakeholders identified from the public sector. In addition, Enterprise, Host-Country Corporation, Investors, Consumers, and Suppliers are the stakeholders in the market environment, while NGO, Local Community, and Host-Country Government are the stakeholders in the nonmarket environment.

Third, as introduced in Chapter 2, Mitchell, Agle, and Wood [1997] developed a descriptive theory of stakeholder salience and then validated it with an empirical study [Agle, Mitchell, and Sonnenfeld, 1999]. In their theory, power, legitimacy, and urgency are extracted as three relationship attributes for stakeholders and a typology of seven categories of stakeholders can be generated through combining these attributes (see Figure 2-2).

For the RuSakOil, using the above theory, most of the previously identified stakeholders including Enterprise, Host-Country Corporation, Investors, NGO, Local Community, and Host-Country Government can be characterized as the Definitive Stakeholders for the Project. Moreover, Consumers and Suppliers can be characterized as the Expectant Stakeholders who may lack of the attribute of power to some degree. This is also a validation for the other two approaches in terms of stakeholder identification.

After going through the basics of the above three approaches, a list of stakeholders for the Project in the running example is now obtained: Enterprise, Host-Country Corporation, Investors, Consumers, Suppliers, NGO, Local Community, as well as Host-Country Government. Counting in the Project itself, there are totally nine stakeholders for this SVN analysis (see Table 3-2).

Table 3-2: Stakeholder Identification for the RuSakOil

Stakeholders	Identification Approach		
	<i>Crawley [2009], Sutherland [2009]</i>	<i>Calvert [1995], Cleland [1998], Winch [2004]</i>	<i>Mitchell, Agle, and Wood [1997]</i>
Enterprise	“Stake” Holders	Internal/Demand; Market	Definitive Stakeholder
Host-Country Corporation	“Stake” Holders	Internal/Demand; Market	Definitive Stakeholder
Investors	“Stake” Holders	Internal/Demand; Market	Definitive Stakeholder
Consumers	Users	Internal/Demand; Market	Expectant Stakeholder
Suppliers	“Stake” Holders	Internal/Supply; Market	Expectant Stakeholder
NGO	Interests	External/Private; Nonmarket	Definitive Stakeholder
Local Community	Beneficiaries	External/Public; Nonmarket	Definitive Stakeholder
Host-Country Government	Institutions	External/Public; Nonmarket	Definitive Stakeholder
Project	The Focal Organization		

From the above table, we observe that Mitchell, Agle, and Wood’s approach [1997] provides less differentiation than the other two approaches. One major reason, as discussed in Chapter 2, lies in that the confusion between “Stakeholder” and “Stakeholder Relationship”—as argued by many sociological theories, Power, Legitimacy, and Urgency are more appropriate to be treated as the properties of “Stakeholder Relationship”, rather than properties of “Stakeholder”—this argument will be discussed in detail in Section 3.2.4.2 for the identification of important stakeholders.

In reality, after brainstorming among researchers and interviewing stakeholders, the initial list for stakeholders could be much longer than that in the example, even with the aid of the above three approaches. However, for technical reasons the number of stakeholders in the SVN analysis should be no more than twenty, mainly bounded by the computational capacity of the modeling platform (of the third step in the framework, see Figure 3-1), which is elaborated later in this chapter as well as in Chapter 5 and 6. Facing this situation, the stakeholders with similar role or in jurisdictional hierarchy will be clustered together to shorten the long list of stakeholders and keep the SVN

computationally manageable. Examples for such a technique can be found in later chapters as well as in Crawley [2009] and Sutherland [2009].

3.2.1.2 Value Flow Definition

Once an appropriate list of stakeholders (including the focal organization hereafter) has been obtained, the next challenge in the first step is to identify the tangible and intangible value exchanges between any two stakeholders to construct a multi-relational network, that is, a SVN. Those bilateral and direct value exchanges are represented by value flows, which can be derived from the specific needs of each stakeholder.

Together with Sutherland [2009], we develop a template to articulate the roles, objectives, and specific needs of each stakeholder step by step, and then those specific needs of each stakeholder are mapped as value flows coming from other stakeholders. Taking the Local Community in the RuSakOil as an example, Figure 3-2 shows how such a stakeholder characterization template looks like.

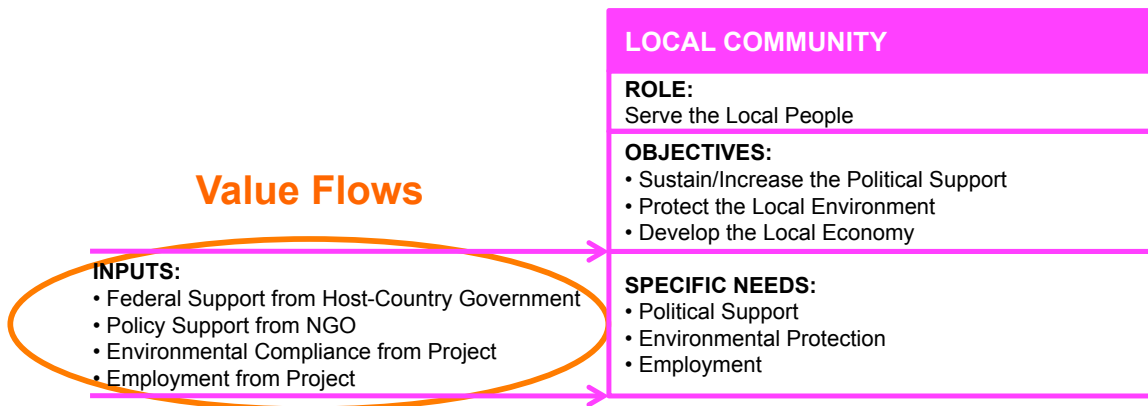


Figure 3-2: Stakeholder Characterization Template for the Local Community

The stakeholder characterization template begins with the top box defining the roles of each stakeholder that are relevant to the focal organization’s activities. Below the roles, the stakeholder’s objectives are extracted from its published goal statements, mission statements, policy and strategy documents, or other official documents. Below the

objectives, the stakeholder's specific needs are refined in the same manner and finally translated into the specific inputs flowing from other stakeholders, that is, the value flows defined above. For example, in Figure 3-2, the Local Community receives four value flows from other stakeholders to fulfill its own specific needs: "Federal Support" from the Host-Country Government, "Policy Support" from the NGO, "Environmental Compliance" from the Project, and "Employment" from the Project.

In the above template, we can observe the logic relationship between all the four parts: From the roles to objectives to specific needs and to value flows, the stakeholder characterization template develops a traceable, consistent, and deepened understanding for how the stakeholders contribute owned resources to and acquire desirable value from each other. More importantly, these bilateral and direct value exchanges, or value flows, derived from such an understanding provide the "building blocks" for the multilateral and indirect value exchanges, or value paths, which can be taken as the basis for further interpreting the impacts of indirect relationships between stakeholders in the SVN, as discussed in Chapter 2. In addition, theoretically, the sum of all the value flows identified in the stakeholder characterization templates forms a complete set of the value transactions within the stakeholder network, and therefore it is unnecessary to conduct a similar but separate exercise to decide each stakeholder's outputs to other stakeholders. Also based on the cognitive characteristics of human beings, in general it is easier to identify the inputs required by one stakeholder than to identify that stakeholder's outputs delivering value to others.

For the RuSakOil, all the stakeholders and the value flows required by each stakeholder are summarized in Table 3-3, after using the template to characterize the other eight stakeholders in term of their roles, objectives, specific needs, and finally the value flows running into them. Note that the names of these value flows tend to be generic and are self-explanatory in this running example, but in the real case study of Chapter 4, it is necessary to give a specific and detailed description for each value flow.

Table 3-3: Stakeholders and Value Flows for the RuSakOil

To Stakeholder	Value Flow	From Stakeholder
Project	Project Approval	Host-Country Government
	Regulatory Approval	Local Community
	Technology	Enterprise
	Workforce	Local Community
	Logistic Support	Host-Country Corporation
	Product Subsystems	Suppliers
	Investment	Enterprise
Enterprise	Future Project Approval	Host-Country Government
	Technology Requirements	Project
	High-Grade Goods	Project
	Low-Grade Goods	Project
	Investment	Investors
	Sales Revenue	Consumers
Host-Country Corporation	Technology Transfer	Project
	Revenue Sharing	Project
	Economic Support	Host-Country Government
Host-Country Government	Political Influence	Host-Country Corporation
	Project Lobbying	Local Community
	Taxes	Project
Local Community	Federal Support	Host-Country Government
	Policy Support	NGO
	Environmental Compliance	Project
	Employment	Project
Investors	ROI	Enterprise
Consumers	Product	Enterprise
Suppliers	Contracts	Project
NGO	Environmental Impact Plan	Project

Now the two challenges, stakeholder identification and value flow definition, have been tackled for the first step of the SVN analysis (see Figure 3-1). In practice, the process of identifying stakeholders and defining value flows should involve the participation of both researchers familiar with these analysis techniques and representatives from each stakeholder with expertise and experience related to relationship management. Note that for modern companies, relationship management, or customer relationship management (CRM) [Chen and Popovich, 2003], is a widely implemented method for managing a company's interactions with customers, and nowadays, there is a trend to extend the

concept of CRM to manage a company’s interactions with other stakeholders than customers only, which is called enterprise relationship management (ERM) [Galbreath, 2002] and consistent with the development of stakeholder theory. In addition, based on different strategic goals of the focal organization, the whole process can be either open or close—when the main goal is to collaborate, this process should keep open and transparent; while when the main goal is to compete, this process should keep close and confidential—for both cases, an awareness is always required for the computational capacity of the modeling platform introduced later.

Based on the set of stakeholders and values flows determined through the above process, the qualitative model of the SVN can now be built up, in the format of “stakeholder maps”, by connecting all the stakeholders with the value flows between them. For the RuSakOil, using the information in Table 3-2 and 3-3, its stakeholder map can be created in Figure 3-3:

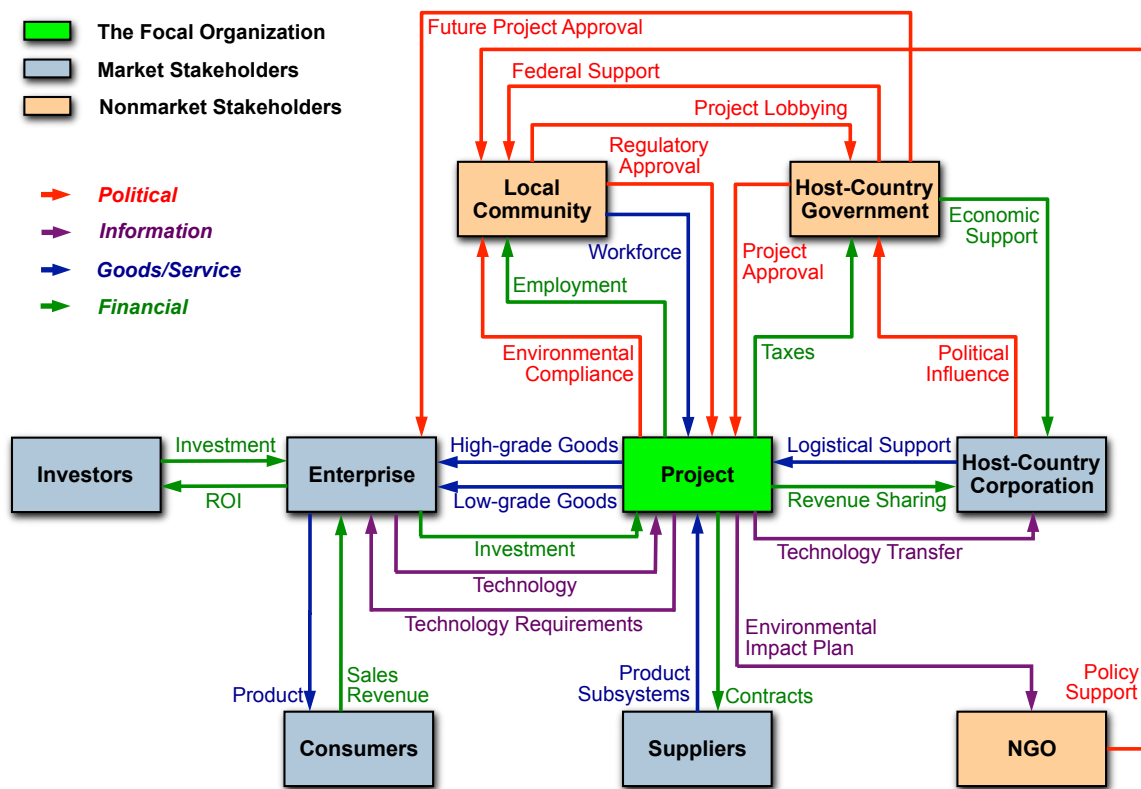


Figure 3-3: Stakeholder Map for the RuSakOil

As shown in the above figure, one attractive feature of the stakeholder maps is the color-coding system for different types of stakeholders and value flows: For stakeholders, the focal organization is colored with light green, the market stakeholders are colored with light blue, and the nonmarket stakeholders are colored with light salmon; For value flows, red color represents the political flows, purple color represents the information flows, blue color represents the goods/service flows, and green color represents the financial flows. Note that classifying the stakeholders by the market and nonmarket environment is based on the argument of Baron [1995] among other scholars in the field of nonmarket strategy, while classifying the value flows by the political, information, goods/service, and financial resources is based on Foa and Foa's [1971, 1974, 1980] resource theory for social and economic exchanges. We design such a color-coding system in the stakeholder maps and applies it to all the case studies in order to discover the connections between the types of value flows and the environment where they are exchanged, as well as other possible principles or patterns for the value exchanges in the stakeholder network.

Another attractive feature of the stakeholder maps is the emergence of indirect value exchanges, or value paths, from those direct value exchanges, or value flows. As mentioned previously, value paths show the possible ways for a group of stakeholders to exchange value in an indirect manner and further can be taken as the basis to study the impacts of indirect relationships in the stakeholder network. For example, Figure 3-4 brings up two value paths, along which different types of value have been exchanged, in the RuSakOil case.

On the left, the Project provides "Employment" to the Local Community, and then the Local Community gives "Project Lobbying" to the Host-Country Government, and finally the Host-Country Government issues "Project Approval" back to the Project; On the right, the Project provides "Environmental Impact Plan" to the NGO, and then the NGO gives "Policy Support" to the Local Community, and finally the Local Community issues "Regulatory Approval" back to the Project. Intuitively, these two value paths are very meaningful for the Project to engage its stakeholders in an indirect way and should

have seen many applications in the real world, especially when some stakeholders are not easy to be engaged directly. However, the identification of all the value paths is not that intuitive and the interpretation for the aggregate impacts of these value paths cannot rely on the intuition either. As such, it is a necessary and important task to find an efficient means to search for the value paths in the stakeholder network as well as develop a comprehensive understanding for their strategic implications in the viewpoint of the focal organization. And the quantitative model of the SVN, which is established in the next step (see Figure 3-1), can complete this task.

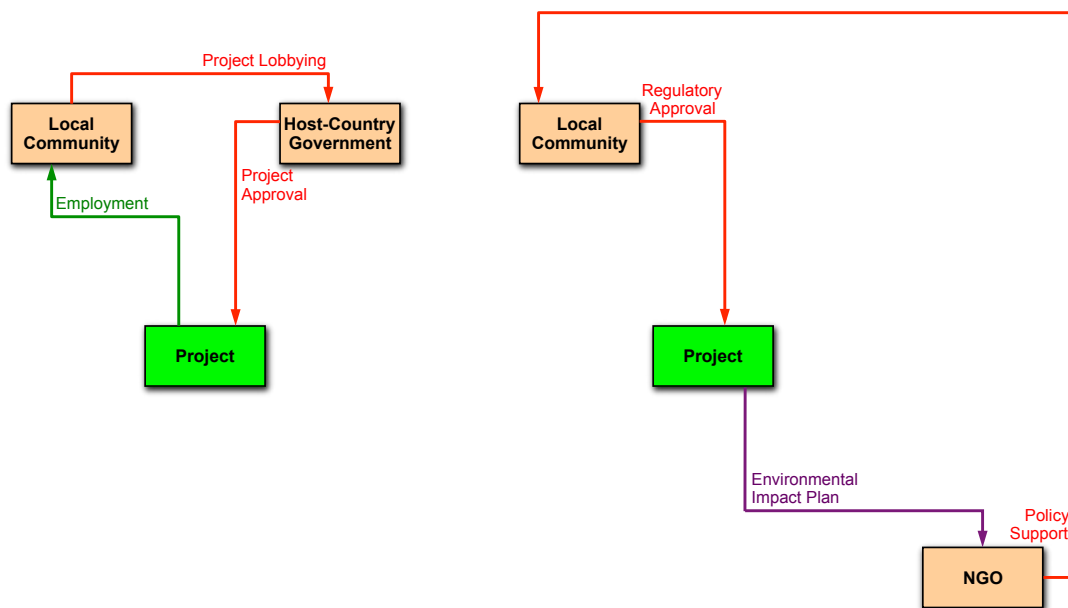


Figure 3-4: Two Examples for the Value Paths in the RuSakOil

The third feature of the stakeholder maps is the similarity between its terminology and that of the Object-Process Diagram (OPD) and the related Object-Process Methodology (OPM) [Dori, 2002], which has been used to visualize the four-step modeling framework for the SVN analysis (see Figure 3-1). In the stakeholder maps, stakeholders are actually the “objects” and value flows are the “processes” of exchanging various resources between stakeholders. This similarity makes it possible and convenient to build the quantitative model of the SVN on the platform of the Object-Process Network (OPN)

[Koo, 2005], a domain-neutral and executable meta-language based on the OPD and OPM. This is discussed in detail in the third step of the framework (see Figure 3-1).

Finally, in the stakeholder map for the RuSakOil (see Figure 3-3), there are totally 9 stakeholders and 27 value flows. As emphasized before, this is a simplified small network only for the purpose of demonstration. For the real cases studied in this dissertation as well as in the collaborative research efforts [Cameron, 2007; Sutherland, 2009], generally the number of stakeholders in the SVN is from ten to twenty, bounded by the computational capacity of the modeling platform (i.e., the OPN). Moreover, as a good rule of thumb, the number of value flows is five to ten times the number of stakeholders in the same network, which means on average each stakeholder has five to ten specific needs, and this observation may be explained by the limits on human capacity for processing information, or the “magic number seven, plus or minus two” [Miller, 1956]. This rule also implies the number of possible value paths in the stakeholder network will increase exponentially with the number of stakeholders or value flows, which poses a great challenge for the OPN modeling platform. In addition, the more stakeholders and value flows are included in the SVN, the more difficult it is to understand the details of the stakeholder map for that SVN. Under this circumstance, there are two ways to improve: One is to decompose the stakeholder maps into multiple views, according to the types of value flows (e.g., Political, Information, Goods/Service, and Financial), or the temporal stages of a project (e.g., Access, Appraise, Select, Define, Execute, and Operate), for both better visibility and more insights gained from the individual views—examples for the decomposition of stakeholder maps can be found in the case studies of Chapter 4 and 6; The other is to aggregate stakeholders with similar roles/functions into several sections and then on a higher level to show the reduced amount of value flows among those sections—example for this technique can be found in Sutherland [2009].

At this point, the qualitative construction of the SVN model has been completed with the formation of stakeholder maps. Before diving into the details of the next three steps in the modeling framework (i.e., Quantifying, Searching, and Analyzing, see Figure 3-1), it is

helpful to recall the three major assumptions for the SVN analysis, in light of the high correlations between these assumptions and the next three modeling steps. Respectively, the first assumption about Relationship Types provides the theoretical basis for scoring value flows and value paths in the step of “Quantifying”; the second assumption about Exchange Patterns provides the theoretical basis for searching for all the value paths beginning from and ending with the focal organization in the step of “Searching”; and the third assumption about Strategic Implications provides the theoretical basis for constructing network statistics from the sample space of value paths in the step of “Analyzing”. In other words, the remaining three steps of the SVN analysis heavily rely on the above assumptions and take the quantitative modeling as their main theme, in order to gain a deeper appreciation for the implications of both direct and indirect stakeholder relationships.

Now the quantitative modeling for the SVN begins with the process of scoring value flows and value paths as described in the next step.

3.2.2 Step Two: Quantifying

“Quantifying” is the second step in the SVN analysis, and as mentioned before, its specific goal is to transform the stakeholder maps into a quantitative model of the SVN through scoring value flows by the perceived utility of the recipient stakeholders and defining the propagation rule of value flows in the stakeholder network to calculate the score of a value path. Such a quantitative model, built upon the additional information collected from a questionnaire for each stakeholder, provides a feasible way to compare the relative importance of value flows and rank the emerging value paths, which can be taken as the basic units to further measure the aggregate impacts of both direct and indirect relationships between stakeholders for the focal organization.

Obviously, for this step, “value flow” and “value path” (see Table 3-4) are two important concepts and have already been discussed many times in this chapter. From the perspective of the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005;

Zafirovski, 2005], a pair of value flows between two stakeholders actually represents the “restricted exchange” [Lévi-Strauss, 1949], which is defined as the two-party reciprocal relationships that may be shown as “ $A \Leftrightarrow B$ ”; While a closed value path, or a value path beginning from and ending with the same stakeholder, actually represents the “generalized exchange” [Bearman, 1997; Ekeh, 1974; Lévi-Strauss, 1963; Malinowski, 1922; Sahlins, 1965a], which is defined as the univocal reciprocal relationships among at least three parties in the exchange situation that may be shown as “ $A \Rightarrow B \Rightarrow C \Rightarrow A$ ” (Note that in some literature this is a special case of generalized exchange, called “network-generalized exchange” [Takahashi, 2000; Yamagishi and Cook, 1993] or “chain-generalized exchange” [Shah and Levine, 2003]).

After going through the essence of the above two concepts, the process to quantify value flows through a stakeholder questionnaire and the process to quantify value paths with the value propagation rule are discussed in detail as below.

Table 3-4: Value Flow vs. Value Path

	Definition	Basis	Implication
<i>Value Flow</i>	The output of one stakeholder and at the same time, the input of another	Specific need of a stakeholder	A pair of value flows between two stakeholders constitutes a “restricted exchange”
<i>Value Path</i>	A string of value flows connecting a group of stakeholders	Value flows between stakeholders	A closed value path constitutes a “generalized exchange”

3.2.2.1 Value Flow Scoring and Stakeholder Questionnaire

Necessity of a Common Framework

A pair of value flows between two stakeholders represents the bilateral and direct value exchanges and can be derived from the specific needs of each stakeholder. As discussed in the last step, we classify all the value flows into four categories: Political, Information, Goods/Service, and Financial. These four categories are coded with different colors in

stakeholder maps and stand for different types of resources for exchanges [Foa, 1971; Foa and Foa, 1974, 1980]. Further, the political and information value flows, or the exchanges for political and information resources, can be taken as an abstraction of social or nonmonetary relationships; While the goods/service and financial value flows, or the exchanges for goods/service and financial resources, can be taken as an abstraction of the economic or monetary relationships.

As discussed in Chapter 2, a common framework is necessary to simultaneously analyze both social (i.e., political and information value flows) and economic (i.e., goods/service and financial value flows) relationships between stakeholders, which are usually at the organizational level instead of being individuals. And we choose the framework of the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005] in order to gain a deep appreciation for the contents of the stakeholder relationships and avoid the separation for different types of relationships. Under the chosen framework from the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005], social relationships are the extension of economic relationships [Coleman, 1990; Emerson, 1976; Homans, 1961], and therefore “concepts and principles borrowed from microeconomics” [Cook, 2000, p. 687] can be applied to conduct “the economic analysis of noneconomic social situations” [Emerson, 1976, p. 336].

Specifically, the classic concept of “utility”¹⁴ in economics is applied in this dissertation to create a mathematical model to compare the relative importance of value flows in the

¹⁴ Since the beginning of last century, there have been lots of debates on the measurability of utility in economics literature [Köbberling, 2006; Moscati, 2012]. Correspondingly, “ordinal utility” [Hicks and Allen, 1934] has gradually gained more popularity, while nowadays the “cardinal utility” is often treated as an outdated idea mainly because of the difficulty of measurement (and behavioral considerations). However, for the analytical purpose, cardinal utility is still usefully applied in a few specific contexts, such as the expected utilities for decision-making under uncertainty [von Neumann and Morgenstern, 1944] and the discounted utilities for intertemporal evaluations [Samuelson, 1937]. In this dissertation, we choose cardinal utility because in Project Phoenix (see Chapter 4), intertemporal evaluations constitute one important dimension of the utility function. Additionally, in other network analysis of social sciences, such as Coleman and Smith [1973], Coleman [1986, pp. 85-136], and Laumann and Knoke [1987, pp. 369-373], cardinal utility has also seen its application in the mathematical models for resource mobilization and deployment between organizations.

stakeholder network: Each value flow, no matter what type it is, will be assigned a numeric score according to the satisfaction level perceived by the stakeholder who receives the benefits from that value flow. These value flow scores are comparable and actually reflect the degrees of desire for stakeholders to be involved in the relevant direct value exchanges. Further, these scores, or the importance levels of value flows, provide a basis to rank the relative importance of value paths, which are the basic units to measure the aggregate impacts of both direct and indirect stakeholder relationships for the focal organization. Based on the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005], here we posit that all the stakeholder relationships are formed by the use of subjective utility analysis and the comparison of alternatives. In the next section of this chapter, some traditional economic principles, such as “diminishing marginal utility” and “utility maximization”, will also be applied to develop a theory for generalized exchange to improve the calculation method for the relative importance of all the value paths in the stakeholder network.

Based on the above discussion, the relative importance of each value flow can be quantified by the perceived utility of the recipient stakeholder. Note that the utility studied in this dissertation is not “ordinal” but “cardinal” [Strotz, 1953], in order to capture not only the ranking but also the strength of preferences for value flows. However, it’s a notoriously difficult task to measure the magnitude of utility differences, and economists argue that utility could not be measured directly but only indirectly, as highlighted by Marshall [1920, p. 78]: “Utility is taken to be correlative to Desire or Want. It has been already argued that desires cannot be measured directly, but only indirectly, by the outward phenomena to which they give rise: and that in those cases with which economics is chiefly concerned the measure is found in the price which a person is willing to pay for the fulfillment or satisfaction of his desire.”

Utility of a Value Flow

We also take an indirect approach to measure the perceived utility for value flows: First, in light of the analysis for stakeholders’ specific needs as well as for the specific contexts

of the Stakeholder Value Network (SVN), several key attributes are defined to characterize the value flows; Second, numerical scales are developed to measure these key attributes and correspondingly a questionnaire is designed to guide the recipient stakeholders to assign a score for each attribute of the value flows coming to them; Third, a combination rule is chosen to integrate the individual attribute scores of each value flow into a single score, that is, the utility of that value flow comprehensively perceived by the recipient stakeholder. One may notice that such an indirect approach for utility measurement is actually a simplified application of the Multi-Attribute Utility Theory (MAUT) [Edwards, 1977; Keeney and Raiffa, 1976], which is a useful tool for decision makers to create a mathematical model and then quantify the desirability of certain alternatives in a logic and consistent way. In addition, there is an implicit assumption to apply the MAUT to quantify the utility of value flows—that is, all the value flows or specific needs of one stakeholder, are independent from each other—this assumption may be too simplified to reflect the real situations and therefore poses a limitation to the approach chosen by us. For example, in the real world, one stakeholder can have some “emergent needs”, which means these needs will not be presented or become more desired until other “existent needs” are not met by other stakeholders.

As summarized by Sutherland [2009], the following is a list of common characteristics when analyzing the specific needs of each stakeholder:

- Intensity of a need
- Source importance in fulfilling a need
- Urgency in fulfilling a need
- Competition in fulfilling a need
- Awareness of a need

Since all the value flows in the network are derived from stakeholders’ specific needs, the above need characteristics can also be taken as the key attributes of value flows. Specifically, “Intensity of a need” characterizes a value flow from the demand side of the recipient stakeholder; “Source importance in fulfilling a need” characterizes a value flow

from the supply side of the recipient stakeholder; “Urgency in fulfilling a need” characterizes the dynamic property of a value flow; “Competition in fulfilling a need” characterizes the interactive property of a value flow; and “Awareness of a need” characterizes the cognitive property of a value flow.

In practice it is not necessary to include all the above five or even more attributes when scoring the perceived utility of value flows, and there always exists a trade-off between better decisions and the burden to collect more information: The more attributes are included, the more detailed scale can be generated to characterize the value flows, which provide the basis for more fine-grained decisions; However, on the other hand, the more attributes are included, the more difficult it becomes for researchers to design the questionnaire, as well as for stakeholders to fully understand the questionnaire and fill out with reliable answers. Based on the experience of previous research [Cameron, 2007; Sutherland, 2009], generally two or three value flow attributes are good enough for conducting the whole Stakeholder Value Network (SVN) analysis, and “Intensity of a need” and “Source importance in fulfilling a need” are the most frequently used ones, which describe the value flows completely from both the demand side and the supply side of the recipient stakeholders. Under some circumstance it’s also important to include other value flow attributes, in consideration of the specific contexts of the Stakeholder Value Network (SVN). For example, in the real large engineering project studied in the next chapter, timing or temporal stage is a sensitive topic for many stakeholders, and therefore “Urgency in fulfilling a need” will be taken as an attribute to characterize the value flows in that project.

For the RuSakOil (see Figure 3-3) in this chapter, all the value flows are characterized by “Intensity of a need” and “Source importance in fulfilling a need”, and these two important attributes as well as their numerical scales are discussed in detail as below. Further, a stakeholder questionnaire is constructed with these attributes and a combination rule is chosen to get a single utility score for each value flow.

The first value flow attribute, “Intensity of a need”, describes the relationship between the satisfaction level of stakeholders and the fulfillment level of their needs, before considering the particular source fulfilling those needs. Inspired by the Kano model [Kano, et al., 1984; Walden, et al., 1993] for customer requirements analysis, Cameron [2007] first proposed a quantitative method to measure the intensity of a stakeholder need, through a questionnaire eliciting stakeholders’ sense of satisfaction when their need is fulfilled and their sense of regret when their need is unfulfilled. Developed by Professor Noriaki Kano of Tokyo Rika University, this model insightfully points out that for some customer requirements, customer satisfaction is not always proportional to how fully functional the product is. Further, Kano sorted the features of a product into three major quality categories (see Figure 3-5), according to the relationship between the satisfaction level of customers and the fulfillment level of their requirements: Must-be (a.k.a. “Basic” or “Threshold”), One-dimensional (a.k.a. “Should-be” or “Performance”), and Attractive (a.k.a. “Might-be”, “Delighter”, or “Excitement”). For example, the brake of a car can be considered as a “Must-be” feature, because increasing the performance of this feature provides diminishing returns in terms of customer satisfaction, however the absence of this feature results in extreme customer dissatisfaction; the fuel economy of a car can be considered as a “One-dimensional” feature, because for this feature more is generally better and less is generally worse; the GPS system of a car can be considered as an “Attractive” feature, because this feature is unexpected by customers but can result in high level of customer satisfaction, and meanwhile its absence does not lead to dissatisfaction.

The above classifications are useful in guiding design decisions in that they indicate “when good is good enough, and when more is better” [Brusse-Gendre, 2002, p. 1]. Through an analog between customer requirements and stakeholder needs, Cameron applied Kano’s categories to classify the needs of stakeholders, and further defined a nonlinear numerical scale to quantify the intensity of different categories of stakeholder needs. It is important to recognize that two major assumptions have been made here: First, customer requirements or product features are concrete and solution-specific part of a design, while stakeholder needs or value flows are abstract and solution-neutral

phenomena, however, it is a reasonable approximation to move from using Kano’s model to rank the features of a design to ranking the needs satisfied by that design, because “the same human behaviors of expectation and excitement are prevalent in both cases” [Cameron, 2007, p. 55]; Second, an anchored nonlinear scale, such as a ratio or log scale, ensures that those “Must-be” value flows will score significantly higher¹⁵ than the “One-dimensional” value flows, which may be important, but not critical. Cameron [2007] also demonstrated that the results of the quantitative SVN models were largely insensitive to the choice of numerical scales for scoring the value flow attributes, through a large amount of sensitivity analyses.

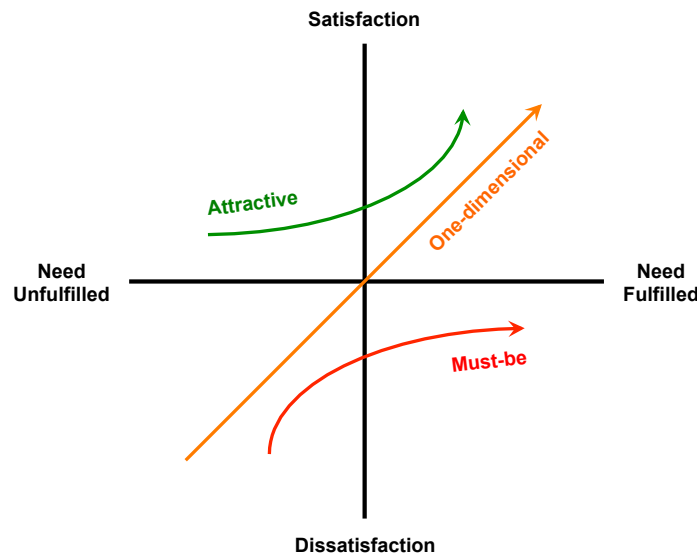


Figure 3-5: Kano Categories for Customer Requirements

Based on Cameron’s work, Sutherland [2009], Seher [2009], and this dissertation improve the questionnaire used for collecting necessary information to classify the stakeholder needs into different Kano categories, as well as the numerical scale to measure the intensity of different categories of stakeholder needs. The improved

¹⁵ Professor Donald Lessard pointed out that this principle is only up to a threshold of “must-be”, after which they may be scored less. In my opinion, the “threshold” of stakeholder’s utility function is similar to the “reference point” in Prospect Theory [Kahneman and Tversky, 1979; Tversky and Kahneman, 1992], and provides an interesting direction for future research on stakeholder behavior.

stakeholder questionnaire asks all the stakeholders the following question regarding the presence or absence of fulfillment of their own needs (see Figure 3-6).

In the questionnaire, stakeholder responses A, C, and E represent the “Attractive”, “One-dimensional”, and “Must-be” value flows respectively (see Figure 3-5), between which responses B and D are falling. All the words in the questionnaire are chosen very carefully to describe both the functional and dysfunctional characteristics of each Kano category as precisely as possible, yet in a simpler and more consistent way compared to the previous versions of stakeholder questionnaire.

<p><u>Need Intensity Questionnaire</u></p> <p>How would you characterize the presence/absence of fulfillment of this need?</p> <p>A. I would be satisfied by its presence, but I would not regret its absence</p> <p>B. I would be satisfied by its presence, and I would somewhat regret its absence</p> <p>C. I would be satisfied by its presence, and I would regret its absence</p> <p>D. Its presence is necessary, and I would regret its absence</p> <p>E. Its presence is absolutely essential, and I would regret its absence</p>
--

Figure 3-6: Stakeholder Questionnaire for Categorizing the Intensity of a Need

Correspondingly, the improved scale for measuring the intensity of different categories of stakeholder needs is listed in Table 3-5. We select a five-point scale, because a three-point scale doesn't provide enough differentiation for stakeholder needs, a four-point scale forces stakeholders to make unrealistic trade-off in some situations as a consequence of lacking a middle position, and a scale with more than five points adds the difficulty for stakeholders to answer the questionnaire.

As discussed before, we also choose a ratio scale to quantify the “need intensity” attribute of value flows, and the scale multiplier between each questionnaire response is roughly set as 1.7 for computational convenience. In addition, one may notice that all the attribute scores are constrained between 0.11 and 0.98, and the reason why defining such a constraint will be explained later when introducing the combination rule integrating

individual attribute scores into a single utility score for a value flow, as well as when discussing the value propagation rule calculating the score of a value path consisting of multiple value flows (see Table 3-4).

Table 3-5: Numerical Scale for Need Intensity Questionnaire

Questionnaire Response	Numeric Score
A	0.11
B	0.19
C	0.33
D	0.57
E	0.98

The second value flow attribute, “Source importance in fulfilling a need”, further describes the relationship between the satisfaction level of stakeholders and the particular sources (i.e., other stakeholders in the network) fulfilling their needs, after considering the fulfillment level of those needs. This attribute emphasizes the diversity of supply—if there is a commodity demanded by one stakeholder, could this stakeholder get it from elsewhere in the market? In addition, the attribute of source importance is similar to the concept of “particularism” (vs. “universalism”) defined by Foa and Foa [1971, 1974, 1980]. From Foa and Foa’s resource exchange perspective, there are two important dimensions to understand the benefits of a value exchange: one dimension is “particularism”, meaning that the resource’s value varies based on its source; and the other dimension is “concreteness”, meaning that how tangible or specific the resource is. For example, among four different types of value flows studied in this dissertation (see Figure 3-3), financial value flows are relatively low in particularism—its monetary value is constant regardless of who provides it. Political value flows, however, is highly particularistic, and its importance depends on its source. Meanwhile, most goods/service value flows are at least somewhat concrete, and less concrete resources, such as some information value flows, provide more intangible benefits. These examples are approximately visualized in Figure 3-7 (Note that it has not been found there is an amazing similarity between this figure and Fig. 1 in Foa [1971, p. 347], until Figure 3-7 is plotted by this dissertation independently).

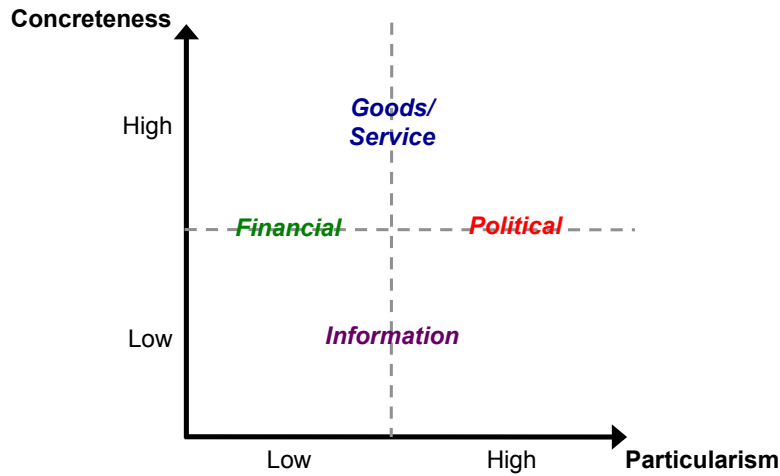


Figure 3-7: “Particularism” and “Concreteness” Dimensions for Four Types of Value Flows

Although “concreteness” is a useful concept to describe the characteristics of value flows, it’s not directly related with the perceived utility of those flows, especially the quantity of utility. That is, some tangible value flows (i.e., high concreteness) could be more desirable than other intangible (i.e., low concreteness) value flows, and meanwhile, some intangible value flows could be more desirable than other tangible value flows. Nevertheless, the concept of “particularism” should not be ignored when quantifying the utility of value flows, particularly because for those flows with high particularism, the recipient stakeholders’ desire level will vary a lot with different value flow sources. Therefore, in this dissertation, “particularism”, or “Source importance in fulfilling a need”, has been chosen as the second key attribute to characterize the value flows, following the first one, “Intensity of a need”. Note that we purposely introduce these two value flow attributes in such an order, to provide a clear and consistent logic for stakeholders to evaluate each value flow coming to them, in the sense that the “Intensity of a need” is more fundamental than the “Source importance in fulfilling a need” by classifying the basic categories of stakeholder needs. Accordingly, the questionnaire for the “source importance” attribute is shown in Figure 3-8.

Source Importance Questionnaire

If this need were to be fulfilled, how important would this specific source be in fulfilling the need?

1. Not important – I do not need this source to fulfill this need
2. Somewhat important – It is acceptable that this source fulfills this need
3. Important – It is preferable that this source fulfills this need
4. Very important – It is strongly desirable that this source fulfills this need
5. Extremely important – It is indispensable that this source fulfills this need

Figure 3-8: Stakeholder Questionnaire for Categorizing the Source Importance in Fulfilling a Need

And the corresponding numerical scale for the source importance questionnaire is listed as below (see Table 3-6). For the same reason discussed previously, we also select a five-point scale for the “source importance” attribute. However, based on the definition for each response in the above questionnaire (see Figure 3-6), a linear scale is more appropriate than a nonlinear scale, and meanwhile, it is a rational assumption that stakeholders can linearly differentiate the importance of multiple sources fulfilling a common need. Similarly, the reason why constraining the scores for all the responses between 0.11 and 0.98 will be discussed later in this section.

Table 3-6: Numerical Scale for Source Importance Questionnaire

Questionnaire Response	Numeric Score
1	0.11
2	0.33
3	0.55
4	0.78
5	0.98

Once obtaining the attribute scores for “need intensity” and “source importance” through the above stakeholder questionnaires and numerical scales (see Figures 3-6, 3-8, and Tables 3-5 ~ 3-6), it comes to the last step to quantify the perceived utility of value flows, that is, choosing a combination rule to integrate the scores of two attributes into one

single utility score for each value flow, which is also called “value flow score”. As shown in Figure 3-9, we choose multiplication operation as the combination rule:

Source Importance Score	5 = 0.98	0.11	0.19	0.32	0.56	0.96
	4 = 0.78	0.09	0.15	0.26	0.44	0.76
	3 = 0.55	0.06	0.10	0.18	0.31	0.54
	2 = 0.33	0.04	0.06	0.11	0.19	0.32
	1 = 0.11	0.01	0.02	0.04	0.06	0.11
		A = 0.11	B = 0.19	C = 0.33	D = 0.57	E = 0.98
		Need Intensity Score				

Figure 3-9: Combination Rule for Integrating Two Attribute Scores into Value Flow Score

In the above figure, those colored grids represent 25 possible combinations of two attribute scores, and the utility score of each grid equals the multiplication of the corresponding “need intensity” score and “source importance” score. For example, if a value flow is ranked as “D” in terms of need intensity and as “3” in terms of source importance, the utility score for that value flow will be 0.31. In addition, note that the grid color changes with the magnitude of value flow scores.

As pointed out before, from the perspective of the Multi-Attribute Utility Theory (MAUT) [Edwards, 1977; Keeney and Raiffa, 1976], the above indirect approach for stakeholder utility measurement can also be described by a two-attribute utility function, which is similar to the concept of production function in economics, in a discrete format (i.e., *Source* = 1, 2, 3, 4, 5 and *Intensity* = 1, 2, 3, 4, 5):

$$Utility = Need Intensity \times Source Importance = (0.11 \times 1.7^{Intensity}) \times (0.11 \times Source) = 0.0121 \times Source \times 1.7^{Intensity}$$

(Equation 3-1)

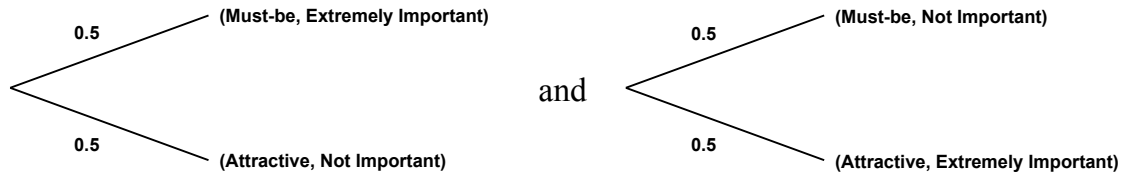
The main reason why a multiplicative utility function is chosen here is to simplify the computation while ensuring positive correlations between utility and those two attribute scales. Moreover, together with the range of [0.11, 0.96] for each attribute scale, the multiplicative function normalizes all the value flow scores within the range of [0, 1], which is consistent with the traditional settings of the utility theory.

One may argue that an additive utility function is even simpler than the multiplicative form. However, assumptions for the additive form are more restrictive: in addition to the Preferential Independence and Utility Independence which have to be satisfied for the multiplicative form, the additive form also requires the Additive Independence. Based on the MAUT, these three independence conditions are defined as below:

- **Preferential Independence:** Attribute X is preferential independent from Attribute Y when changes in the preference order of Y do not change the preference order of X.
- **Utility Independence:** Attribute X is utility independent from Attribute Y if the utility for X does not change when Y is changed.
- **Additive Independence:** Attributes X and Y are additive independent if the paired preference comparison of any two lotteries, defined by two joint probability distributions on X×Y, depends only on their marginal probability distributions.

The above three conditions become stronger increasingly, from the Preferential to Utility and to Additive Independence. Recalling the concepts for the “need intensity” and “source importance” attributes of value flows discussed previously, it is straightforward to understand that the Preferential Independence and Utility Independence are satisfied. However, the Additive Independence does not hold—for simplicity, assuming that the “need intensity” attribute only includes Must-be and Attractive, and the “source

importance” attribute also includes only Extremely Important and Not Important—a stakeholder will not be indifferent for the following two lotteries, or those two lotteries will not be equally preferred by a stakeholder:



The above explanation provides a theoretical support for the value flow scoring method used in this dissertation. In the real world, a stakeholder’s utility function can be calibrated by the Conjoint Analysis [Green and Srinivasan, 1978; Orme, 2005] or the Analytical Hierarchy Process (AHP) [Saaty, 1999, 2001], among other mathematical psychology tools. Meanwhile, it is more realistic to assume that different stakeholders have different utility functions, and even for the same stakeholder, the utility function may also change with time. But all of these improvements would require more computational/analytical resources and can only be achieved when the complexity of the SVN model is reasonably managed, which will be discussed later in this chapter. More importantly, the relative significance of value flows matters more than their absolute scores, in light of the purpose of this dissertation. von Mises [1944, p. 26] once mentioned: “There are no such things as absolute values, independent of the subjective preferences of erring men.” In addition, Cameron [2007] went a step further and pointed out that another merit of such a scoring system for these subjective utilities is to model the “what-if” scenarios of value exchanges between stakeholders, instead of the actual value transmissions in the network.

After elaborating the details of value flow scoring and stakeholder questionnaire from both theoretical and practical aspects, now this method is applied to the running example (see Figure 3-3) discussed earlier in this chapter: the specific questionnaire for the RuSakOil is shown in Questionnaire A-3-1 (see the Appendix), to characterize the value flows in terms of both the “Intensity of a need” and “Source importance in fulfilling a

need”; and the answered questionnaire as well as the combined utility score for each value flow are exhibited in Table A-3-1 (see the Appendix).

More Discussions on Stakeholder Questionnaire

Before introducing the value propagation rule for value path scoring, there are two more questions worthwhile for further discussion: Firstly, how should the stakeholder questionnaire be answered? And secondly, how should the value flow scores from the questionnaire be validated?

Considering the first question, several individuals knowledgeable about the project should answer the stakeholder questionnaire, and ideally there will be at least one person representing each stakeholder. In this way the fairness merit of the SVN analysis can be guaranteed and there will be no inputs from “an overarching modeler”. When assigning the attributes scores to each value flow, it is important that all the participants put themselves in the shoes of the recipient stakeholder for that flow, and it should be better to assign all the “need intensity” scores before assigning the “source importance” scores to those value flows, in order to keep the participant’s mind “focused on one scoring rubric rather than alternating back and forth” between two attribute scales, as well as to avoid the coupled responses for different attributes which will remove “some of the useful texture in the final results of the value network analysis” [Sutherland, 2009, pp. 70-71]. Once the attribute scores of each value flow are obtained, one can apply an appropriate method, such as the Delphi method developed by the RAND Corporation [Brown, 1968; Dalkey and Helmer, 1963; Linstone and Turoff, 1975; Sackman, 1974], to reconcile differences of the scores among all the participants. An independent researcher familiar with the methods can act as a facilitator for the reconciling process, and such an interactive process will be stopped after a pre-defined criterion (e.g., number of rounds, achievement of consensus, stability of results) is met. Finally, the mean or median scores of the last round of questionnaire survey determine the attribute scores of each value flow and then the value flow scores in the stakeholder network.

Considering the second question, it will be helpful to validate the value flow scores, or at least the relative ranking of value flows, after a final set of scores are determined. There are three ways to achieve this goal: First, one can conduct a cross validation by interviewing different individuals or teams within one stakeholder. Second, the relative ranking of some value flows can be validated by proxy data sources. For example, in the SVN analysis for the Space-based Earth Observations, Sutherland [2009] used the number of House Committee hearings in NASA's six science categories to validate the preference of the U.S. government for those categories. Last but not least, sensitivity analysis is also a possible way—flag those questionable scores first, and then change their range to see how sensitive the final results of the SVN analysis would be to those scores—this technique can save time and efforts in the first step of analysis. Basically, the objective of validation is not to rigorously prove the validity of all the value flow scores, which are “the outcome of human arbitrariness” and reflect “all the shortcomings and weaknesses of their authors” [von Mises, 1944, p. 26]. Instead, the objective here is to “perform enough verification to establish general confidence in the model” [Sutherland, 2009, p. 74], as well as to transparently record the subjective preferences of stakeholders and surface some implicit assumptions—they are beneficial for further improving the SVN model with more information or better knowledge. In addition, similar to the arguments from System Dynamics [Forrester, 1964; Sterman, 2000], only one possible state of the world will be revealed with time, so a physical calibration against data is not possible—however, the key difference between System Dynamics and the SVN analysis lies in whether the system model is dynamic or static: System Dynamics is an approach to understanding the behavior of complex systems over time, and deals with the internal feedback loops (reinforcing or balancing) and time delays (stock and flow) that affect the behavior of the entire system; While for the SVN analysis, its main goal is to understand the exchange and structure properties of multi-relation networks as well as the strategic implications of these properties, therefore under the limitation of analytical and computational resources, the system model is static and more like a “snapshot” for the value exchanges between stakeholders at a specific temporal stage.

For the RuSakOil case, five researchers at MIT filled out the stakeholder questionnaire (see Questionnaire A-3-1), and the final score of each value flow (see Table A-3-1) was determined after a three-round Delphi process. Two representatives from the Project provided a cross-validation for the value flow scores, especially the relative ranking of value flows for the Project and the Enterprise.

3.2.2.2 Value Path Scoring and Value Propagation Rule

As observed before, one attractive feature of the stakeholder maps is the emergence of the multilateral and indirect value exchanges, or value paths, from those bilateral and direct value exchanges, or value flows (see Figure 3-4). And then the concepts of value flows and value paths are contrasted in terms of definition, basis, and implication (see Table 3-4). In particular, value paths show the possible ways for a group of stakeholders to exchange value in an indirect manner and further can be taken as the basis to study the impacts of indirect relationships in the stakeholder network. Therefore, after a detailed discussion on value flow scoring and stakeholder questionnaire, the next task before the completion of the quantitative SVN model is to define a propagation rule for value flows, in order to score the value paths in the network.

Cameron [2007] first defined a multiplicative rule to calculate the score of a value path. According to this rule, the path score equals the product of the scores of all the value flows along that path. Taking one of the two value paths highlighted in Figure 3-4 as an example (see Figure 3-10), the score of this specific value path can be calculated through Equation 3-2:



Figure 3-10: Example for the Multiplicative Rule of Value Propagation in the SVN

$$\text{Value Path Score} = \prod (\text{Value Flow Score}) = 0.54 \times 0.10 \times 0.96 \approx 0.052 \quad (\text{Equation 3-2})$$

Before explaining the rationale behind the above multiplicative rule, it is important to point out that by virtue of the previous method for value flow scoring (see Figure 3-9), all the scores of value flows have been normalized within the range of [0, 1], which is consistent with the traditional settings of the utility theory. Moreover, there is no value flow scored with negative utility in the SVN (see Table A-3-1), or in the terminology of graph theory, the SVN is a “Signed Graph” [Cartwright and Harary, 1956] with positive signs only, and this fact is decided by the context of this dissertation—all the value flows are derived from the specific needs of each stakeholder—however, it does not mean “detriment” cannot be modeled in the SVN. As argued by Freeman [1984, p. 122], the stakeholder relationships include three basic types, that is, “positive”, “negative”, and “neutral”. We agree with Freeman but uses a different strategy to simplify the situation: for a “positive” relationship from Stakeholder A to Stakeholder B, it can be represented by a value flow running from A to B; for a “negative” relationship from Stakeholder A to Stakeholder B, it can be represented by a value flow running from B to A; and for a “neutral” relationship between Stakeholder A and Stakeholder B, it can be represented by two or more value flows running in both directions between A and B. In other words, the directions of value flows in the SVN are always the same as the directions toward which the actual benefits are delivered, and by doing this, “detriment” is also able to be reflected in the SVN. For example, in the RuSakOil (see Figure 3-3), the value flow of “Environmental Compliance” from the Project to the Local Community is beneficial for the Local Community, but may be perceived by the Project as “detriment”. Meanwhile, from the perspective of this dissertation, it would be redundant to use another flow with negative value in the SVN to show the “Environmental Requirements” from the Local Community to the Project.

Based on the above observations, there are three reasons to define a multiplicative rule for the calculation of value path scores:

- First, similar to the value flow scores, the score of a value path reflects the relative importance of an indirect value exchange for all the stakeholders along

that path. A multiplicative rule ensures that all the value path scores—the products of the scores of all the value flows on those paths—remain bounded within the range of [0, 1], which is consistent with the traditional settings of the utility theory.

- Second, heuristically, under the multiplicative rule, longer paths tend to have lower scores, indicating the fact that with the increase of path length, it becomes more and more difficult to engage stakeholders along the value path, constrained by the cognitive capability of each stakeholder. Meanwhile, it also becomes more and more difficult to manage those stakeholders because of more considerations as well as more uncertainties associated with a longer path. In another word, the multiplicative rule reflects both the benefits (through the subjective utilities of each stakeholder, or the value flow scores) and the costs of a value path at the same time, and is supported by the argument from Harary, Norman, and Cartwright [1965, p. 159] among others [Jackson, 2008]: “There may be a distance (length of path) beyond which it is not feasible for u to communicate with v because of costs or distortions entailed in each act of transmission.”
- Third, the multiplicative rule simplifies the calculation for the value path scores, as it does for the calculation of value flow scores. In the future, with more computational/analytical resources, the quantification for the benefits and costs of a value path can be completed by different operation rules, for instance, showing “more value accumulated along the longer paths” and “more difficulties to manage the longer paths” respectively.

Additionally, the multiplicative rule for path score calculation requires that the lowest value flow score should be larger than 0—otherwise the value path score will always equal to 0 no matter what else value flows are included in that path (see Figure 3-9); and the largest value flow score should be smaller than 1—otherwise the value path score will keep unchanged no matter how many value flows with a score of 1 are added to that path (see Figure 3-9). This is also the reason why previously defining a range constraint for those two attribute scales (see Tables 3-5 and 3-6). Although the choice of 0.11 and 0.96

is at the discretion of this dissertation, however, such a choice does guarantee some important characteristics for the indirect value exchanges within the SVN.

For simplicity, the multiplicative rule for value propagation is also applied to calculate the value path scores for the RuSakOil (see Figure 3-3). In the fourth section of this chapter, a more rigorous foundation for the calculation of value path scores—a utility model of generalized exchanges—will be established, and correspondingly, an improved mathematical method will be developed to calculate the scores of value paths. And such an improved method, rather than the multiplicative rule discussed here, will be put in an application for all the case studies in later chapters of this dissertation.

Once the value flows are scored and a value propagation rule is defined, the quantitative construction of the SVN model has been completed. As highlighted previously, the assumption about relationship types—monetary and nonmonetary relationships between stakeholders can be analyzed in a common framework because social exchanges are the extension of economic exchanges—provides the theoretical justification for scoring value flows and value paths in this step. Based on such a quantitative model, the next step is to search for all the direct and indirect value paths in the SVN, which can be then taken as the basis for a network analysis in the last step.

3.2.3 Step Three: Searching

“Searching” is the third step in the SVN analysis, and as mentioned before, its specific goal is to search for all the value paths beginning from and ending with the focal organization as the sample space for a statistical network analysis. These closed value paths, or “value cycles” defined by this dissertation, can be taken as the basic units to further measure the aggregate impacts of stakeholder relationships—both direct and indirect ones—on the strategic behavior of the focal organization, which is the Project as chosen in the first step of the SVN analysis. Note that in order to avoid ambiguity, we do not use the term of “value loops” [Cameron, 2007; Sutherland, 2009] for those special value paths, because “loop” and “cycle” are two different concepts from the perspective

of graph theory: the former means “an edge that joins a single endpoint to itself” [Gross and Yellen, 2003, p. 55], while the latter means “a closed path of length at least one” [Gross and Yellen, 2003, p. 51]. The difference between these two concepts is important for the discussion in Chapter 5.

This section first reviews several key terms for the SVN analysis, and then further explains the theoretical basis for value path search. After that, the software platform and modeling details for searching all the value paths beginning from and ending with the same stakeholder are discussed.

By far the following key terms have been defined in this chapter:

- **Value Flow:** The output of one stakeholder, and at the same time, the input of another;
- **Flow Score:** The subjective preference or perceived utility for a value flow ranked by the recipient stakeholder;
- **Value Path:** A string of value flows connecting a group of stakeholders;
- **Path Score:** The product of the scores of all the value flows along the path;
- **Value Cycle:** The value path beginning from and ending with the same stakeholder, namely, the focal organization;
- **Cycle Score:** The product of the scores of all the value flows along the cycle.

As emphasized prior to the quantitative construction of the SVN model, the assumption of “Exchange Patterns”, which roots in the Social Exchange Theory (SET) [Emerson, 1976; Homans, 1958; Lévi-Strauss, 1949; Malinowski, 1922], sets up the theoretical foundation for this step of the SVN analysis: The multilateral and indirect value exchanges, namely, generalized exchanges [Bearman, 1997; Ekeh, 1974; Lévi-Strauss, 1963; Sahlins, 1965a], widely exist in the strategic behavior of modern organizations [Olson, 1965; Shah and Levine, 2003; Westphal and Zajac, 1997]. For example, in Figure 3-4, the closed value paths (i.e., value cycles) bring forward two generalized exchanges meaningful for the Project to engage its stakeholders in an indirect manner, especially

when some stakeholders—in this case they are the Host-Country Government and Local Community, respectively—are not easy to engage directly. More importantly, project managers confirmed that among others, these two generalized exchanges have seen wide applications in the real world.

In Freeman’s now-classic book, *Strategic Management: A Stakeholder Approach*, generalized exchanges between organizations, as well as the relationship networks consisting of such indirect exchanges, are also acknowledged (see Figure 3-11). However, Freeman [1984, p. 58] argues that: “... little is known in the way of formulating strategies for utilizing such networks in a positive and proactive fashion. Little is known, prescriptively, about what range of alternatives is open to managers who want to utilize such an indirect approach to dealing with stakeholders.” Almost thirty years later, a series of efforts made by MIT researchers [Cameron, 2007; Cameron, Crawley, Feng, and Lin, 2009; Cameron, Crawley, Loureiro, and Rebentisch, 2008; Crawley, 2008, 2009; Feng, Crawley, de Weck, et al., 2010; Feng, Crawley, de Weck, Keller, Robinson, and Lin, 2012; Feng, Crawley, de Weck, Lessard, and Cameron, 2012; Fu, Feng, Li, Crawley, and Ni, 2011; Sutherland, 2009] including this dissertation, aim to challenge Freeman’s argument and utilize “such an indirect approach” to deal with stakeholders in “a positive and proactive fashion”, through developing a rigorous method to quantitatively measure the strategic impacts of those generalized exchanges between stakeholders. Moreover, from an analytical perspective, generalized exchanges in the form of value cycles, provide the means for gaining an in-depth understanding on how value is created, exchanged, and delivered throughout the whole stakeholder network, which is not often obvious or intuitive, especially when the size of network (i.e., number of stakeholders and value flows) becomes large. Based on such an understanding, generalized exchanges can help the focal organization allocate its limited resources by identifying the stakeholder needs that are not currently satisfied well.

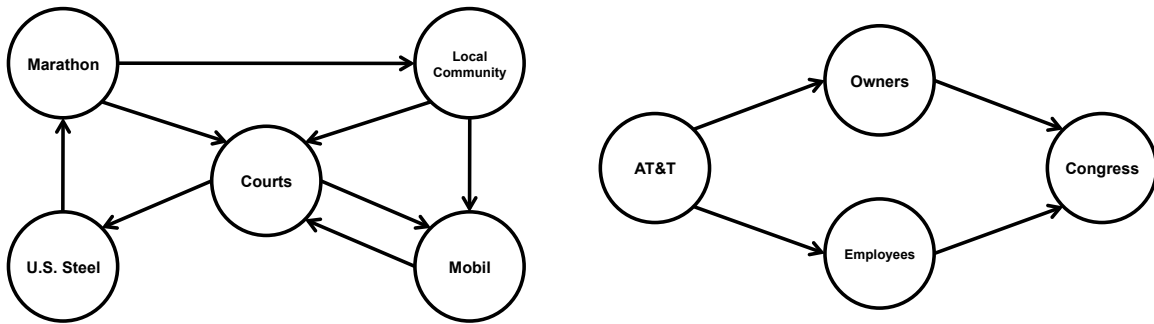


Figure 3-11: Freeman's Examples for Generalized Exchanges [Adapted from Freeman, 1984, p. 60]

Now the major task of the third step in the SVN analysis boils down to searching for all the value cycles beginning from and ending with the focal organization. As pointed out during the qualitative construction of the SVN model, the terminology of the stakeholder maps (see Figure 3-3) is similar to that of the Object-Process Diagram (OPD) and the related Object-Process Methodology (OPM) [Dori, 2002], where stakeholders are the “objects” and value flows are the “processes” of exchanging various resources between stakeholders. Such a similarity provides the feasibility and convenience of running the quantitative SVN model on the platform of the Object-Process Network (OPN), a computer software program built upon the OPD and OPM.

Developed by the MIT System Architecture Group [Koo, 2005], OPN is a graphical, domain-neutral, and executable meta-language for the purpose of representing, generating, and manipulating simulation models. It is especially suitable for the enumeration and analysis of large, complex system architectures, and can also be applied to search and calculate the value cycles in the stakeholder networks.

Taking the RuSakOil (see Figure 3-3) as an example, the user interface of the OPN modeling platform is snapshotted in Figure 3-12: The left window visualizes the SVN model with “objects” (see green rectangles) and “processes” (see blue ovals); the middle window records the entire search process, including both intermediate steps and final results, for all the value cycles of the focal organization (i.e., the Project); and the right windows exhibit the details of each step in the form of graphs and tables.

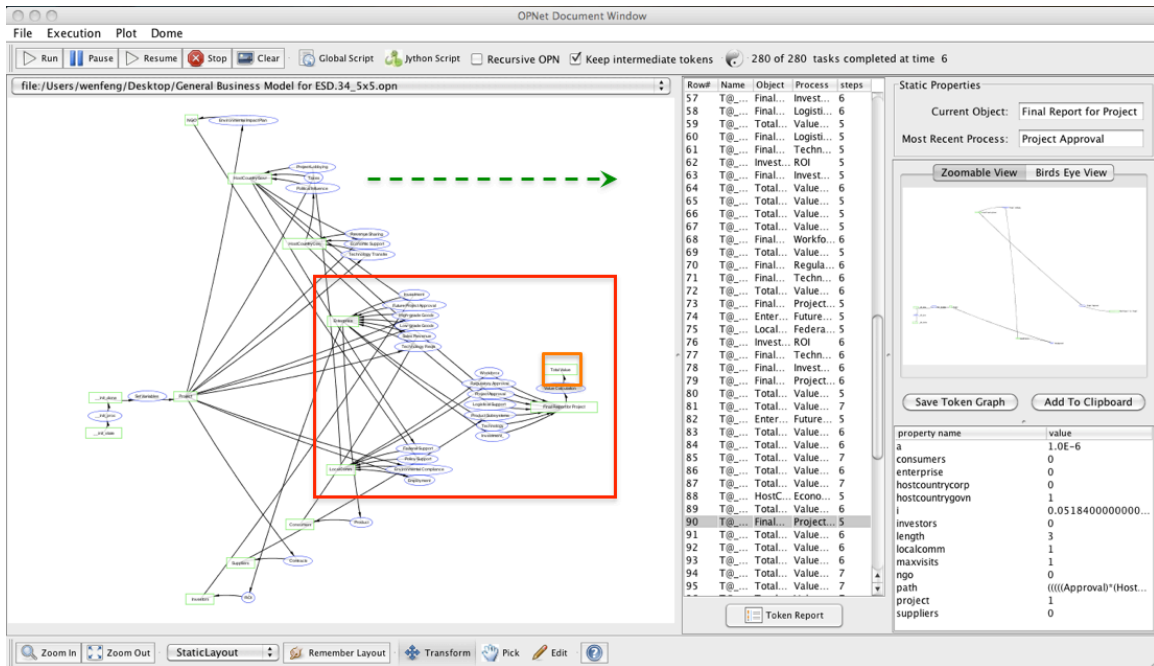


Figure 3-12: OPN Model for the SVN of the RuSakOil

Specifically, in the left window, the model breaks the SVN at the place of the focal organization (i.e., the Project) and then unfolds the whole network from left to right: the Project, eight other stakeholders, and the Project. At the same time, value flows are grouped together around the recipient stakeholders, standing for the specific needs of each stakeholder. Further, value flow scores obtained from the stakeholder questionnaire and the multiplicative rule defined previously for value propagation, are coded behind the corresponding objects and process. Figure 3-13 shows the zoom-in view of one portion (see the red box in Figure 3-12) of the SVN model.

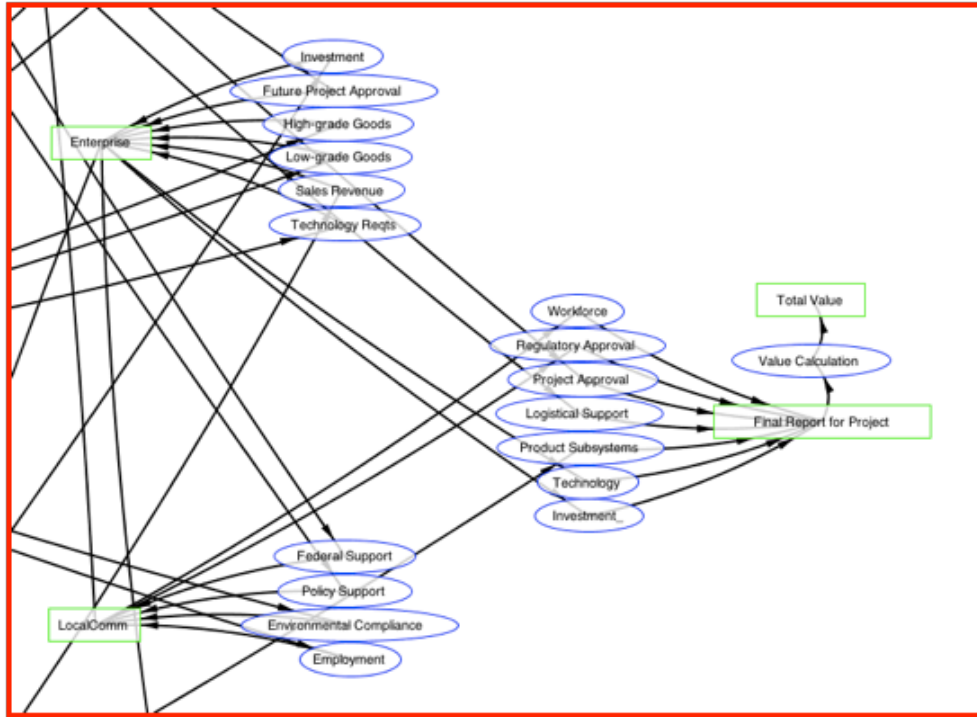


Figure 3-13: Zoom-In View of the OPN Model

When the SVN model is running, the program codes search the unfolded network from the left side to the right side (see the dotted green arrow in Figure 3-12) and report all the value cycles to the final vertex (see the orange box in Figure 3-12) as soon as the search algorithm finds such a cycle for the focal organization (i.e., the Project). In general, the shorter cycles appear earlier than the longer cycles in the search results, because the mechanism of Breath-First-Search (BFS) [Bollobás, 1998; Diestel, 2005; Hochbaum, 2008], which will be discussed in detail in Chapter 5, is employed in the search algorithm of the OPN. Figure 3-14 shows the modeling report exported from the final vertex: Each row in the left table represents one unique value cycle for the focal organization (i.e., the Project), and the important information about this cycle, such as the involved stakeholders and value flows, cycle length, and cycle score, is summarized in the graph and table to the right. For example, the current graph in Figure 3-14 visualizes the value cycle in the 30th row of the report, which is the same cycle highlighted in the search process (see Figure 3-12).

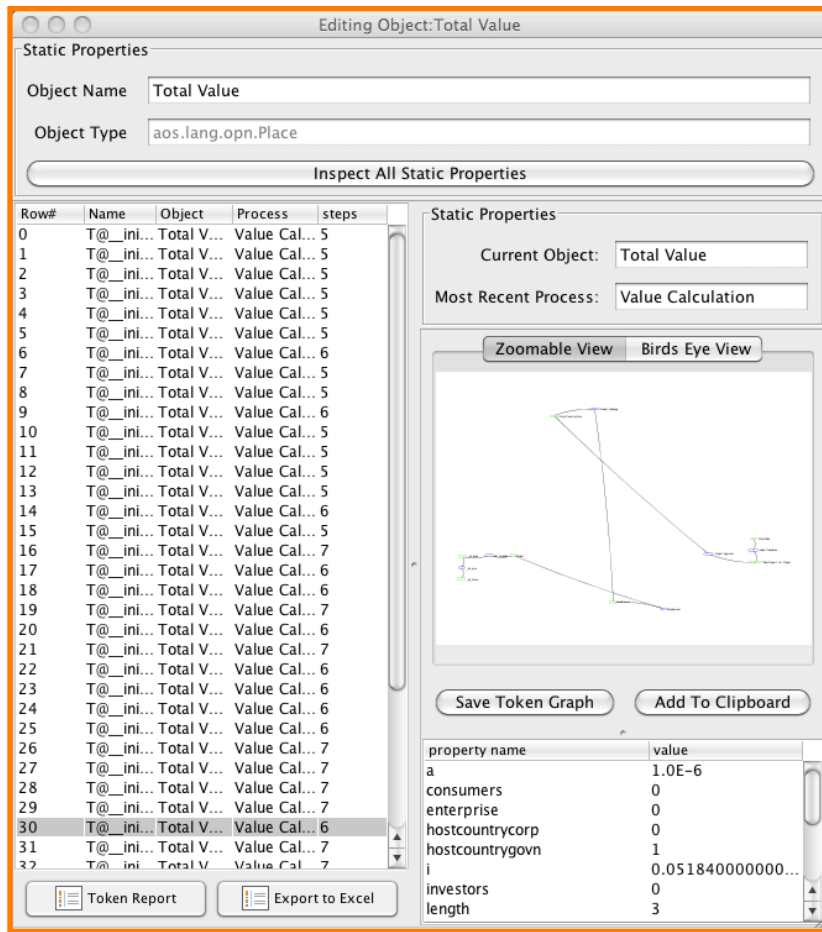


Figure 3-14: Final Vertex Report for All the Value Cycles of the Project

From the above report, we observe that the total number of value cycles for the Project is small—there are totally 43 value cycles that will be discussed later in this section—and therefore the running time of the SVN model on the OPN platform is negligible. However, in the real world the SVN models are often much larger with more stakeholders and/or more value flows, and correspondingly the running time is a big concern, which will be further treated in the complexity analysis for the search algorithms in Chapter 5. In order to ensure that these larger models are still solvable with the limitation of computational resources, usually the following four types of constraints will be integrated into the quantitative model of the SVN:

- **Internal Assets:** This constraint defines the mechanism for stakeholders to convert their inputs to outputs, in the form of “internal assets”, which are the categorized resource pools to connect each stakeholder’s inputs with the same category of outputs;
- **Simple Cycle:** This constraint requires that no stakeholder is revisited along the value cycle excluding the start/end one (i.e., the focal organization);
- **Cycle Score $\geq a$:** This constraint sets the lower bound for the score of a value cycle, where “a” is between 0 and 1 (for the previous quantitative model);
- **Cycle Length $\leq k$:** This constraint sets the upper bound for the length of a value cycle, where “k” is between 2 and n (n is the total number of stakeholders).

It is straightforward to understand that the above constraints shrink the sample space of value cycles for the focal organization and therefore reduce the dimensionality of the SVN model. More importantly, the proposition of these constraints is also justified by their strategic implications:

First of all, in the existing SVN model, each stakeholder’s inputs are matched to its outputs freely along a value cycle. However, such a treatment is not realistic for various reasons—a good one is that when the value flows are highly concrete, such as most goods/service value flows (see Figure 3-7), their connectivity is often restricted and the connection between them should be carefully examined. For example, if a stakeholder needs an input value flow labeled “raw materials from manufacturer”, and meanwhile provides an output value flow labeled “equipment specifications to contractor”, these two value flows should not be connected as one part of a value cycle because they have clear, specific, but different contents. Stated in a more fundamental way, the existing SVN model does not factor in the causal relationships between flows when linking them into a cycle. As such, the concept of “internal assets” is developed to ensure that the value cycles from the SVN model have realistic causation by specifying the conversion or production process between each stakeholder’s input and output value flows—rather than getting connected directly, now the input and output value flows will be connected through different resource pools named “internal assets”, and within the same “internal

assets”, the input value flows can be freely matched to the output value flows. For instance, domestic political capital, project support, and treasury are common “internal assets” for nonmarket stakeholders (i.e., government, NGO, and so on), while human resource, CAPEX, OPEX, revenue, legal eligibility, and corporate strategy are common “internal assets” for market stakeholders (i.e., enterprise, project, and so on). The case study in Chapter 4 will illustrate more details about the application of these “internal assets”. With this technique, a lucid logic is presented for the existence of each value cycle and the reason why stakeholders are engaged in a generalized exchange is also partially explained.

Second, the requirement that no stakeholder except the focal organization is visited more than once along the value cycle, is identical to the premise of “simple cycle” often implied in modern graph theory [Bollobás, 1998; Diestel, 2005; Gross and Yellen, 2003; Hochbaum, 2008; Weinblatt, 1972], or the “elementary cycle/circuit” finding numerous applications in electrical engineering and communication theory [Danielson, 1968; Johnson, 1975; Szwarcfiter and Lauer, 1976; Tarjan, 1972]. In this dissertation, the requirement for “simple cycle” has more practical meaning: First, as highlighted before, the system model in the SVN analysis is static and more like a “snapshot” for value exchanges among stakeholders at a specific temporal stage, and therefore the dynamic process of value accumulation, in the format of visiting a stakeholder multiple times, will not be considered; Second, a simple cycle exactly represents the standard form of “generalized exchange” and has been taken as the basic units to measure the impacts of stakeholder relationships in the network—any value cycle with a stakeholder visited more than once can actually be interpreted as the combination of several simple cycles—if it is allowed to visit a stakeholder multiple times, some simple cycles will be counted more than others, and obviously there is no point to do so.

Third, as introduced before, all the value flow scores have been normalized between 0 and 1, and under the multiplication rule for value propagation (see Equation 3-2), the score of a value cycle equals the product of the scores of all the value flows along that cycle—therefore the cycle scores also remain bounded within the range of [0, 1].

Moreover, according to the utility theory, the value cycles with higher scores are interpreted more important than those with lower scores, which make it possible to set up a lower bound of cycle scores to filter out the relatively less important value cycles to save more computational resources. Obviously such a lower bound should be chosen between 0 and 1, however the choice of the lower bound is open to the critique of being arbitrary, because in this dissertation the perceived utility of each value flow for the recipient stakeholder has not been benchmarked with the conjoint analysis or other mathematical psychology tools.

Last but not least, from the perspective of graph theory, the length of a value cycle is another key attribute associated with the value cycle, in addition to the cycle score. Generally the cycle length is defined as the number of value flows included in that value cycle, and further, based on the requirement of “simple cycle” in the SVN, the shortest length of a value cycle equals two, which is corresponding to the direct or restricted exchange between two stakeholders, while the longest length of a value cycle equals the total number of stakeholders in the network, which is corresponding to the indirect or generalized exchange involving all the stakeholders. As discussed in the multiplication rule for value propagation, with the increase of the cycle length, it becomes more and more difficult to engage stakeholders along that value cycle facing the constrained cognitive capacity of each stakeholder, and meanwhile, it also becomes more and more difficult to manage those stakeholders because of more considerations as well as more uncertainties associated with a longer path. Therefore, similar to those value cycles with too low scores, it is not necessary to include the value cycles with too long length in the SVN analysis, especially when the computational resources is always limited. But different from choosing the lower bound of cycle scores, the choice of an appropriate upper bound of cycle length is not arbitrary and will be discussed in detail in Chapter 5.

For the RuSakOil (see Figure 3-3) in this chapter, the SVN model is very small and there are totally 43 value cycles, which can be found on the OPN platform in a time-efficient manner. Hence only the second constraint of “simple cycle” is added to the OPN model of the SVN—for the first constraint, the causation between value flows along a value

cycle can be easily checked one by one and all the illogical or inconsistent value cycles will be removed manually; and for the third and fourth constraints, neither the lower bound of cycle scores or the upper bound of cycle length is necessary in this case.

After all the unique and valid value cycles are identified from the quantitative SVN model, many interesting and meaningful analyses can be conducted to interpret the strategic implications of both direct and indirect stakeholder relationships for the focal organization. As stressed prior to quantifying the SVN model, the assumption about strategic implications—for example, stakeholder power is the outcome of both exchange relations and network positions—provides the theoretical basis for constructing network statistics from the sample space of value cycles and defining network measurements for the importance of stakeholders as well as other metrics of interest, from the standpoint of the focal organization.

3.2.4 Step Four: Analyzing

This is the last step of the SVN analysis, and as mentioned before, its specific goal is to define network measurements and construct network statistics in order to study the strategic implications of the SVN for that focal organization, such as critical value cycles, important stakeholders, important value flows, important outputs from and important inputs for the focal organization, and so on. These strategic implications, from the perspective of the Social Exchange Theory (SET), are the outcome of both exchange relations and network positions [Blau, 1964; Emerson, 1972; Molm, 1990], and we argue that value cycles (i.e., the value paths beginning from and ending with the focal organization), can be taken as the basic unit to measure such an outcome. On one hand, the value cycles discovered from the quantitative SVN model, along with their scores, provide a feasible way for the focal organization to compare the relative importance of all the exchange relations, including both direct and indirect ones, with other stakeholders; On the other hand, the value cycles also simultaneously capture the information about each stakeholder's position in the SVN—for example, the occurrence of a specific stakeholder in all the value cycles for the focal organization, will obviously vary with its

network position. Therefore, in the last step of the SVN analysis, all the value cycles will be chosen as the sample space for constructing network statistics and then studying the strategic implications of the SVN for the focal organization.

3.2.4.1 Critical Value Cycles

Once all the unique and valid value cycles are identified, one of the most straightforward implications is the relative importance of these value cycles for the focal organization, in terms of the cycle scores calculated in the last step. For the RuSakOil (see Figure 3-3) in this chapter, there are totally 43 value cycles for the Project, and Figure 3-15 shows the score distribution of those value cycles (see the green dotted curve), as well as the corresponding length of each value cycle (see the blue column).

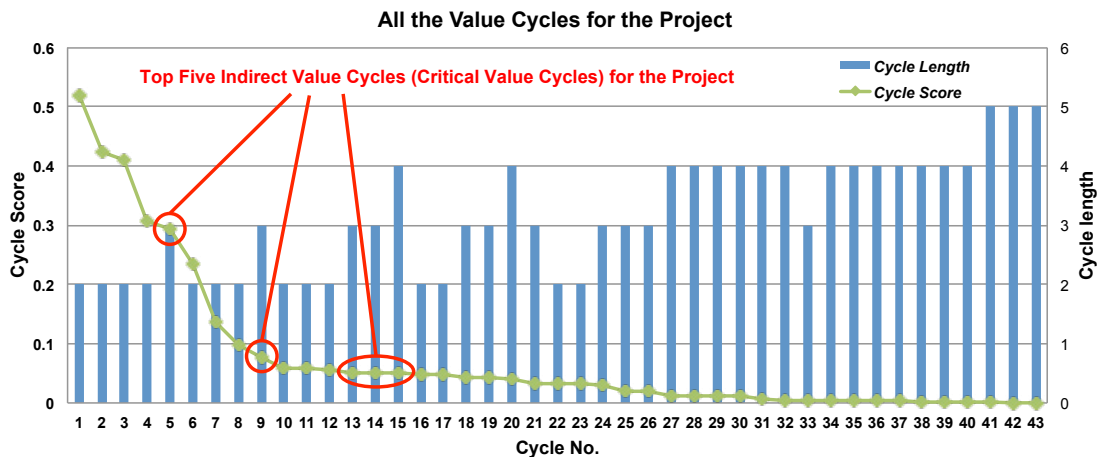


Figure 3-15: Score and Length of All the Value Cycles for the Project

From the above figure, we observe that the highest cycle score is around 0.5 and more than 60% (28 out of 43) of value cycles have a score lower than 0.05, which implies a majority of value cycles are not easy to be differentiated with cycle scores, using the combination rule shown in Figure 3-9, or in other words, using the two-attribute utility function shown in Equation 3-1. This situation may change when introducing more attributes into the utility function of value flows, and Chapter 6 will discuss more details on the relationship between the number of utility attributes and the differentiability of

value cycles in terms of their scores, especially for those networks with a large number of stakeholders and value flows.

In addition, we observe that cycle scores tend to decrease with the increase of cycle length. This observation is consistent with the earlier assumption in this chapter to choose the multiplicative rule for value flow propagation in the stakeholder network. Interestingly, there are also some “unusual” cycles that have much higher scores than other value cycles with the same length. We argue that these “unusual” cycles actually present the opportunities for the focal organization to engage its stakeholders in an indirect way, particularly when it is difficult to engage them directly. For the RuSakOil (see Figure 3-3), the top five indirect value cycles for the Project are circled in red in Figure 3-15, and Figure 3-16 uncovers the details of each cycle. In particular, it is worthwhile to mention that the third value cycle in Figure 3-16, “Project => (Revenue Sharing) => Host-Country Corporation => (Political Influence) => Host-Country Government => (Project Approval) => Project,” was a successful strategy taken by an international energy company in a real multi-billion offshore oil project in a foreign country, which can be seen as a mild validation of this SVN analysis. In this dissertation, these high-leverage indirect value cycles are called “Critical Value Cycles” hereafter.

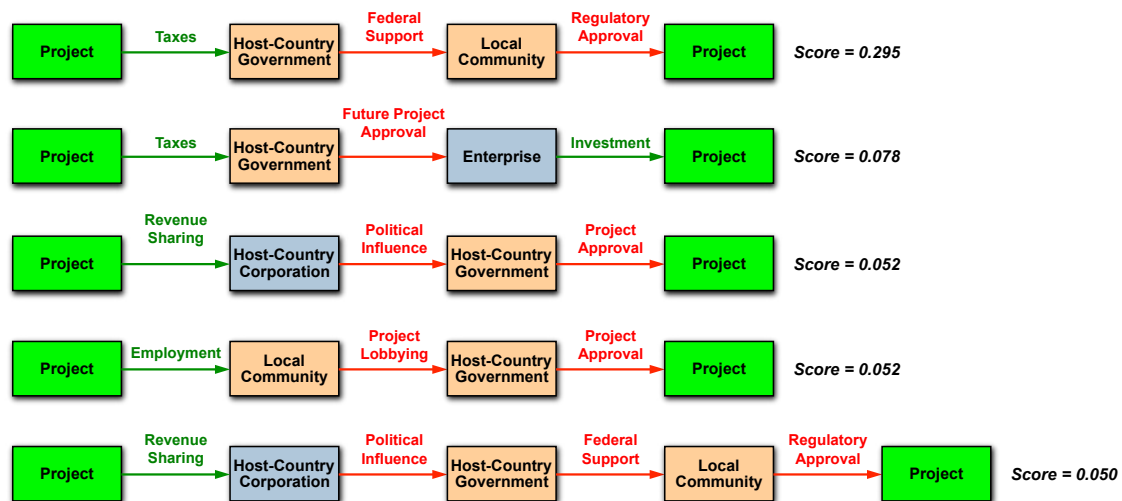


Figure 3-16: Top Five Indirect Value Cycles for the Project

3.2.4.2 Important Stakeholders

The second implication from the SVN analysis is the relative importance of each stakeholder, or the Weighted Stakeholder Occurrence (WSO) [Cameron, 2007; Sutherland, 2009], in terms of the occurrence of that stakeholder in all the value cycles for the focal organization, weighted by the corresponding cycle scores (see Equation 3-3). As highlighted in Chapter 2, the word “Importance” here should be interpreted from a descriptive or instrumental perspective, instead of a normative one [Donaldson and Preston, 1995], which is often a focus in the field of business ethics—more specifically, Corporate Social Responsibility (CSR) and Corporate Social Performance (CSP) [Carroll, 1999; Clarkson, 1995; Hillman and Keim, 2001; Phillips, 1997; Wheeler, Colbert, and Freeman, 2003; Wood, 1991].

$$\text{Weighted Stakeholder Occurrence (WSO)} = \frac{\text{Score Sum of the Value Cycles Containing a Specific Stakeholder}}{\text{Score Sum of All the Value Cycles for the Focal Organization}}$$

(Equation 3-3)

Built upon the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005], the WSO defined in the SVN analysis (see Equation 3-3) also emphasizes the exchange aspects of stakeholder relationships, with the inclusion of structural consideration—the subjective utilities of each stakeholder in all specific value exchanges with other stakeholders have been factored into the scores of value flows and then into the scores of value cycles, while the frequency of stakeholders’ appearance in all the value cycles for the focal organization is clearly a measurement for the structural characteristics of the stakeholder network—because of these two features, we coin a more intuitive name for the WSO, that is, “Exchange Centrality I”, which implies the combination of both exchange and structural properties, or the integration of “Resource Power” and “Positional Power” in Handy’s words [1993]. Moreover, in order to honor Professor Edward F. Crawley who initiated the research in this dissertation, “Exchange Centrality I” is also called “Crawley Centrality I”. Note that the name “Exchange Centrality II” or “Crawley Centrality II” is reserved for the Network Weighted Stakeholder Occurrence (NWSO) introduced in Chapter 5 and 6.

It is worthwhile to highlight again two major developments, from the exchange networks in the Social Exchange Theory (SET) to the stakeholder networks in the SVN analysis, as discussed in Chapter 2: First, exchange networks generally are single-relation networks (i.e., simple graphs), while stakeholder networks are multi-relation networks (i.e., multiple graphs), and the WSO aims to measure the interaction of multiple exchange relationships, or the exchange of multiple types of resources, at the same time; Second, exchange networks mainly study the restricted exchanges between actors in the network, as argued by Emerson [1976, p. 358]: “such networks tend to be composed of linked two-way exchange relations,” while stakeholder networks also examine those generalized exchanges, which are similar to the concept of “weak ties in diffusion processes” [Granovetter, 1973, p. 1363].

Based on the definition of the WSO and using the Equation 3-3, Figure 3-17 shows the calculated relative importance of each stakeholder for the Project in the case of RuSakOil (see Figure 3-3):

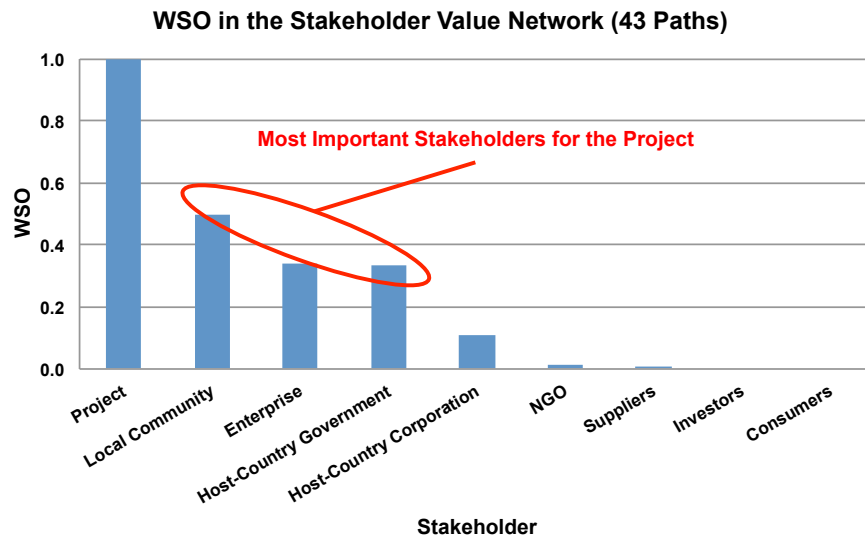


Figure 3-17: Weighted Stakeholder Occurrence (WSO) for the Project

Since the Project is taken as the focal organization and will definitely appear in every value cycle in the sample space, it is straightforward to understand that the WSO of the Project equals to 1.0. Also from the above figure, the most three important stakeholders

can be identified as Local Community, Enterprise, and Host-Country Government, respectively—a short explanation is that the stakeholder with a higher WSO will have more effect on turning the focal organization’s outputs into good inputs, through the possible value cycles. Considering the RuSakOil is a simplified running example, we will not elaborate more details about the implications of the WSO, until in Chapter 4, for a large real-world engineering project (i.e., Project Phoenix), interesting comparisons will be made between the WSO derived from three different stakeholder models (i.e., Manager’s Mental Model, “Hub-and-Spoke” Model, and the SVN model), the individual contribution from exchange and structural properties of the stakeholder network on the WSO will be extracted, and the corresponding strategic implications for the focal organization will also be discussed.

3.2.4.3 Important Outputs and Inputs

Similar to the WSO, two more network statistics [Cameron, 2007; Sutherland, 2009] are defined to measure the relative importance of the outputs from and the relative influenceability of the inputs for the focal organization, i.e., Weighted Output Occurrence (WOO) and Weighted Input Occurrence (WIO), respectively (see Equation 3-4 and 3-5):

$$\text{Weighted Output Occurrence (WOO)} = \frac{\text{Score Sum of the Value Cycles Beginning from a Specific Output}}{\text{Score Sum of All the Value Cycles for the Focal Organization}} \quad \text{(Equation 3-4)}$$

$$\text{Weighted Input Occurrence (WIO)} = \frac{\text{Score Sum of the Value Cycles Ending with a Specific Input}}{\text{Score Sum of All the Value Cycles for the Focal Organization}} \quad \text{(Equation 3-5)}$$

Figure 3-18 and 3-19 summarize the modeling results of the WOO and WIO for the Project in the case of RuSakOil (see Figure 3-3):

- WOO helped identify that the top four high-leverage outputs from the Project are “Taxes” to Host-Country Government, “Employment” to Local Community, “Environmental Compliance” to Local Community, and “High-Grade Goods” to Enterprise. An output with a higher WOO, will have a greater effect on improving

the inputs to the Project at the end of value cycles—if the Project has additional resources to increase the levels of its outputs, WOO suggests a reasonable order for those resources to be allocated.

- WIO helped identify that the top three affectable inputs to the Project are “Regulatory Approval” from Local Community, “Investment” from Enterprise, and “Project Approval” from Host-Country Government, because if the Project increases all its outputs by one unit, WIO indicates how much each input for the Project would increase accordingly—by contrasting the WIO with the normalized scores of the input value flows for the Project, the gap between the expected levels of Project’s needs (i.e., normalized value flow scores) and the affectable levels of these needs by the Project itself (i.e., the WIO) can be visualized in Figure 3-20—from this figure, it can be inferred that “Project Approval” from the Host-Country Government and “Product Subsystems” from the Suppliers are potentially two problematic inputs for the Project, in terms of the gap between the Project’s expectation and its actual ability to ensure these needs met through all the value cycles in the stakeholder network.

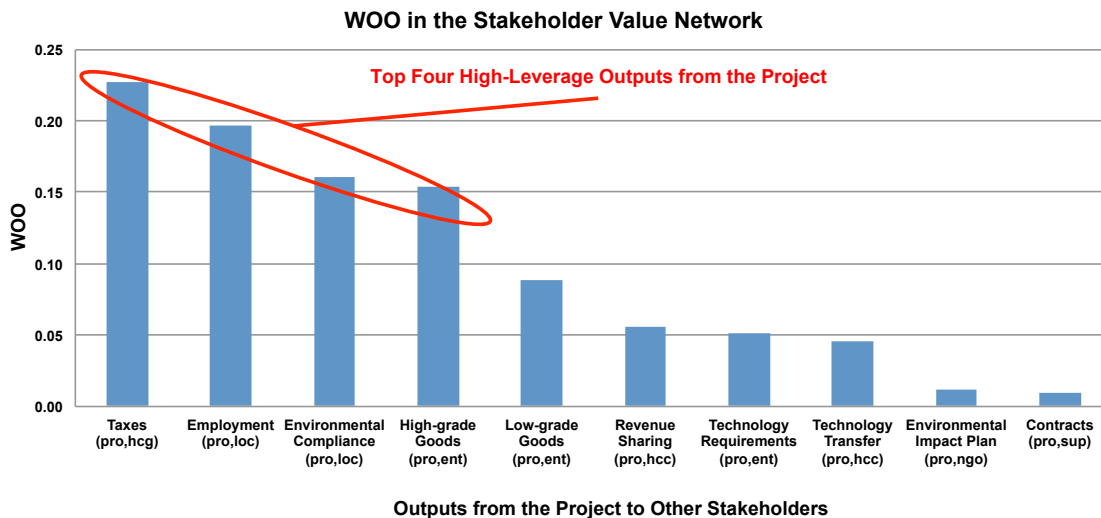


Figure 3-18: Weighted Output Occurrence (WOO) for the Project

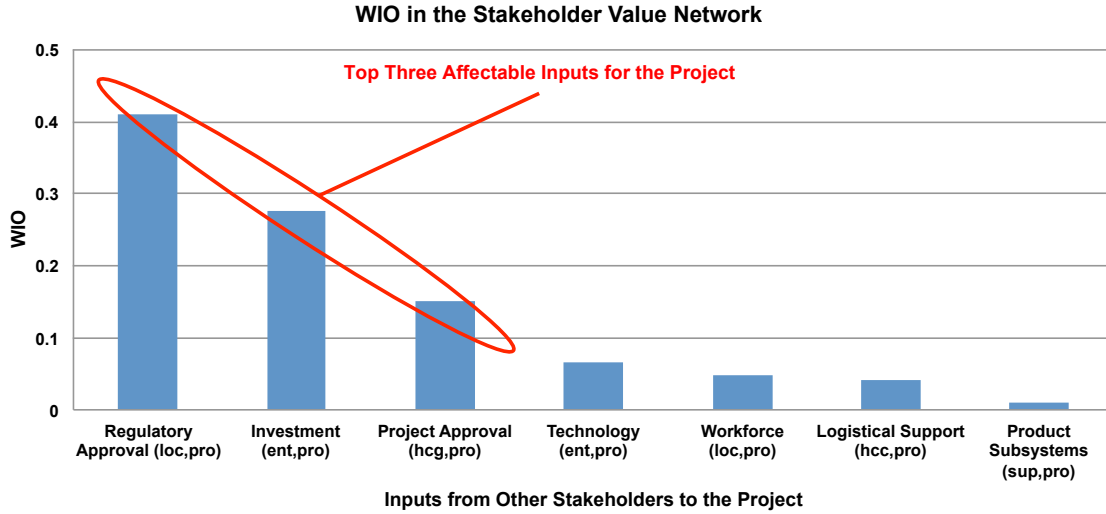


Figure 3-19: Weighted Input Occurrence (WIO) for the Project

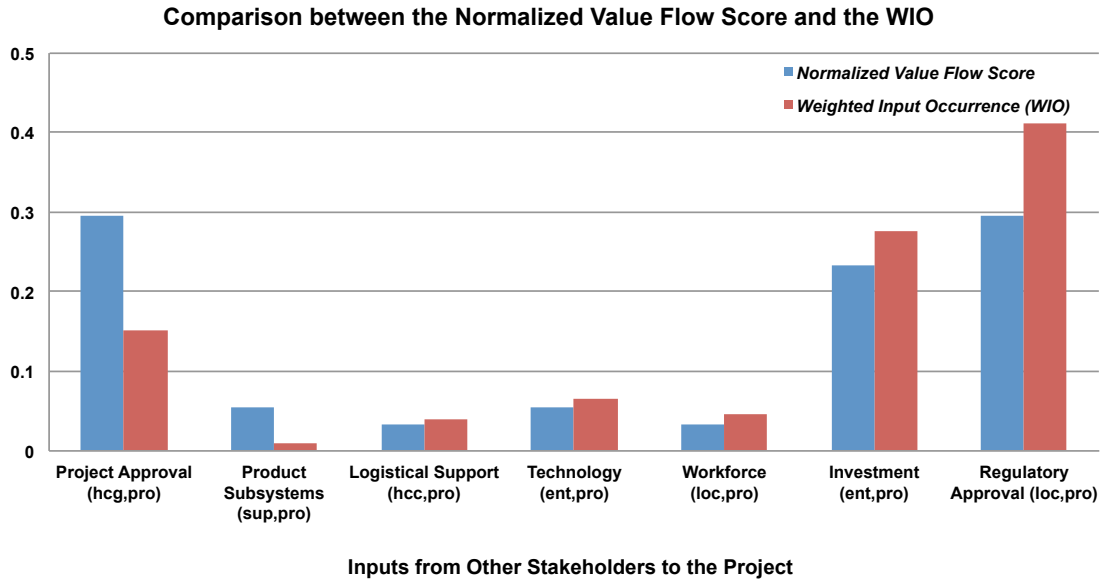


Figure 3-20: Comparison between the Normalized Value Flow Score and the WIO

Further, from rows to columns, Table 3-7 details the conversion matrix from the Project’s outputs to its inputs, by summing the scores of all value cycles between each pair of the output and input of the Project. Meanwhile, the WOO and WIO can also be obtained

through adding all the row elements and column elements together, respectively, based on their definitions (see Equation 3-4 and 3-5).

Table 3-7: Conversion Matrix between the Project’s Outputs and Inputs

Project Input Project Output	Project Approval (hcg,pro)	Regulatory Approval (loc,pro)	Investment (ent, pro)	Workforce (loc, pro)	Technology (ent, pro)	Logistical Support (hcc,pro)	Product Subsystems (sup,pro)	SUM (Rank)
Technology Requirements (pro,ent)	0.000	0.000	0.041	0.000	0.010	0.000	0.000	0.051 (7)
High-grade Goods (pro,ent)	0.000	0.000	0.124	0.000	0.029	0.000	0.000	0.154 (4)
Low-grade Goods (pro,ent)	0.000	0.000	0.071	0.000	0.017	0.000	0.000	0.088 (5)
Revenue Sharing (pro,hcc)	0.016	0.015	0.004	0.002	0.001	0.018	0.000	0.055 (6)
Technology Transfer (pro,hcc)	0.013	0.012	0.003	0.001	0.001	0.015	0.000	0.045 (8)
Taxes (pro, hcg)	0.093	0.089	0.024	0.010	0.006	0.006	0.000	0.228 (1)
Employment (pro,loc)	0.016	0.157	0.004	0.018	0.001	0.001	0.000	0.197 (2)
Environmental Compliance (pro, loc)	0.013	0.128	0.003	0.015	0.001	0.001	0.000	0.160 (3)
Contracts (pro, sup)	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010 (10)
Environmental Impact Plan (pro,ngo)	0.001	0.009	0.000	0.001	0.000	0.000	0.000	0.012 (9)
SUM (Rank)	0.151 (3)	0.411 (1)	0.275 (2)	0.047 (5)	0.065 (4)	0.041 (6)	0.010 (7)	1.000

3.2.4.4 Important Value Flows and Manageable Network Complexity

A natural extension of the concepts of WOO and WIO is the Weighted Value Flow Occurrence (WVFO) [Cameron, 2007; Sutherland, 2009], which aims to measure the relative importance of each value flow, through counting the weighted occurrence of that value flow in all the value cycles for the focal organization (see Equation 3-6). Note that in this dissertation, WOO, WIO, and WVFO have all been normalized for the convenience of comparison, while WSO has not been normalized, mainly for the purpose of benchmarking the WSO of the focal organization always as 1.0.

$$\text{Weighted Value Flow Occurrence (WVFO)} = \frac{\text{Score Sum of the Value Cycles Containing a Specific Value Flow}}{\text{Sum (Score Sum of the Value Cycles Containing a Specific Value Flow)}}$$

(Equation 3-6)

Figure 3-21 shows the modeling results of the WVFO of all the 27 value flows in the case of RuSakOil (see Figure 3-3). Value flows associated with higher WVFO can be

interpreted to have more resource significance and structural advantage in the stakeholder network from the perspective of the focal organization.

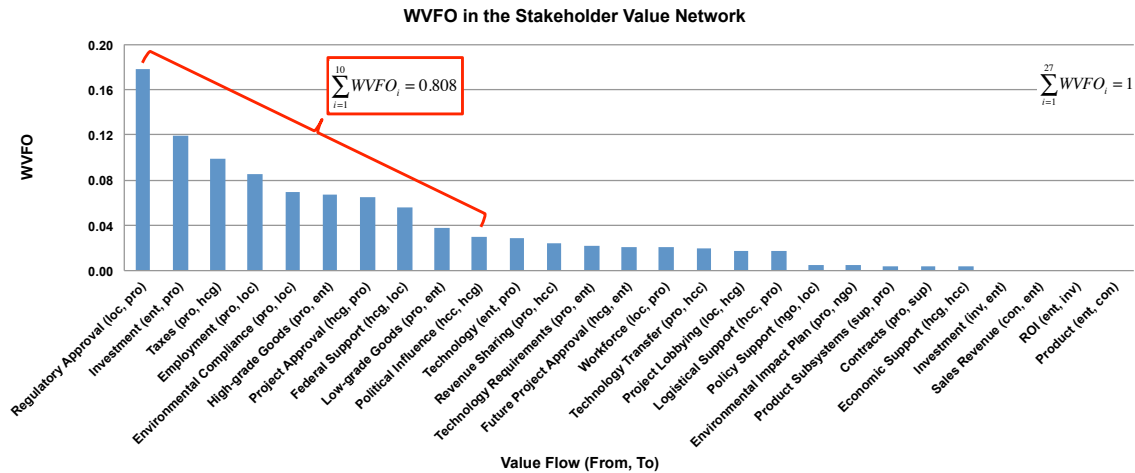


Figure 3-21: Weighted Value Flow Occurrence (WVFO) for the Project

Based on Figure 3-21, it is interesting to observe that less than half value flows (10 out of 27) are responsible for more than 80% of the total value. Using these top ten value flows, together with the important stakeholders identified previously by the WSO (i.e. Exchange Centrality I or Crawley Centrality I), a smaller SVN consisting of fewer stakeholders and value flows can be constructed. Within this smaller network model, more analytical and/or computational resources will be available to deal with more details of the organizational structure and hierarchy of stakeholders as well as their heterogeneous utility functions for value exchanges in the network. In other words, a combination of the WVFO and the WSO can be used by the focal organization to manage the complexity of stakeholder networks, and meanwhile provide the basis for more fine-grained decisions regarding stakeholders. Specifically, the guidelines on managing the network complexity and the principles for hierarchical modeling of the SVN are the focus of Chapter 5 and 6 in this dissertation, with a case study for China’s Energy Conservation Campaign [Fu, Feng, Li, Crawley, and Ni, 2011].

3.2.4.5 Stakeholder Balance

The previous statistics for the SVN, including the Critical Value Cycle, WSO, WOO, WIO, and WVFO, are all established on the sample space of value cycles for the focal organization, in order to measure the strategic implications of vertices (i.e., stakeholders), edges (i.e., value flows), and cycles (i.e., value cycles) in a multidigraph (i.e., SVN).

Now the last statistic in this chapter, i.e., Stakeholder Balance, will break all the value cycles in the sample space into pairwise value paths between the focal organization and other stakeholders, and calculate the score sum of the resulting paths on each direction—from the focal organization to other stakeholders, and from other stakeholders to the focal organization—as the indicators for the strength balance between the focal organization and its stakeholders in terms of value transactions. The creation of this concept has benefited from the study of “Structural Balance” [Cartwright and Harary, 1956; Harary, 1965] in graph theory, which is one of the three main sources for the network analysis in social sciences, argued by Cook and Whitmeyer [1992, p. 115] (another two are social anthropology and sociometry).

Figure 3-22 and 3-23 show the calculated Stakeholder Balance in the RuSakOil (see Figure 3-3), from all the direct transactions as well as from both direct and indirect transactions, respectively. It is straightforward to understand that the direct transactions between the Project and other stakeholders are obtained from the decomposition of the restricted exchanges ($A \leftrightarrow B$) in the network, while the indirect transactions are obtained from the decomposition from the generalized exchanges ($A \Rightarrow B \Rightarrow C \Rightarrow A$). The main objective for differentiating indirect transactions from direct ones and having such a comparison is to highlight the changes from the traditional stakeholder model, i.e., the “Hub-and-Spoke” Model, to the networked stakeholder model, i.e., the SVN, as discussed in Chapter 2. More comparisons between these two types of stakeholder models and further discussions on the strategic implications of those changes will be followed by the case study of Project Phoenix in Chapter 4.

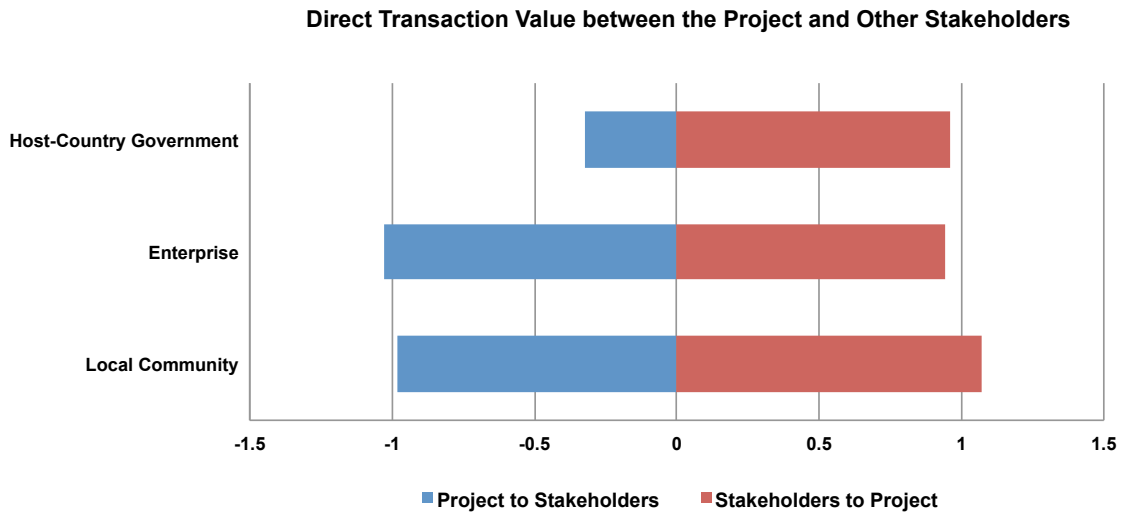


Figure 3-22: Stakeholder Balance from Direct Transactions

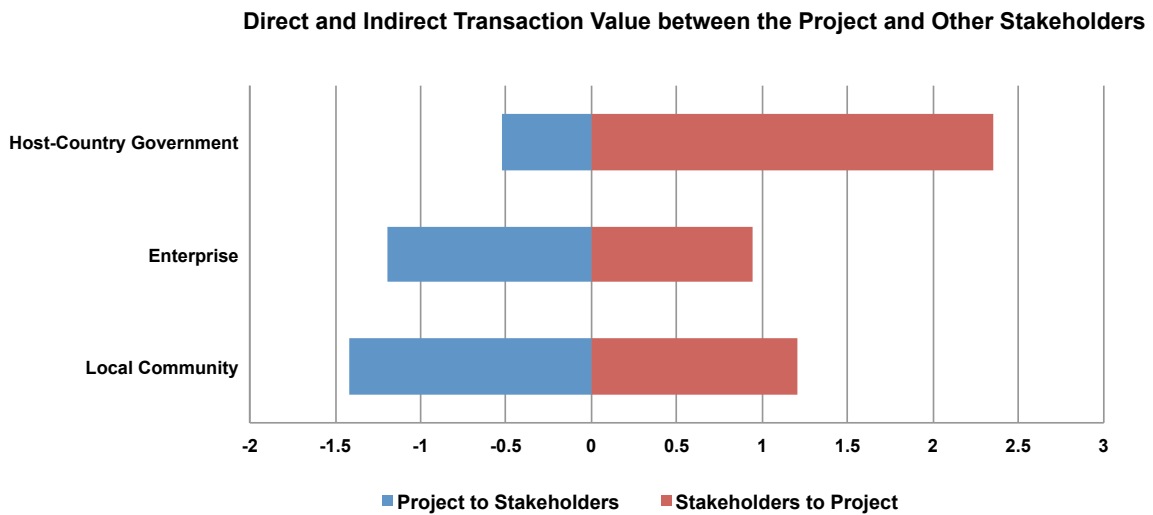


Figure 3-23: Stakeholder Balance from Direct and Indirect Transactions

Note that in Figure 3-22 and 3-23, for the purpose of demonstration, only the three most important stakeholders identified by the WSO, i.e., Local Community, Enterprise, and Host-Country Government, are selected to show their balance with the focal organization,

i.e., the Project. In addition, the length of blue bars is proportional to the transaction value from the Project to other stakeholders, and the length of red bars is proportional to the transaction value from other stakeholders to the Project. Specifically, for the balance where the blue bar is longer than the corresponding red bar, the Project provides more value to a stakeholder than it needs from that stakeholder, which indicates that the Project occupies an advantageous position because of the imbalance nature of the transaction value between two of them; and vice versa for the balance where the red bar is longer than the corresponding blue bar.

Comparing Figure 3-22 with Figure 3-23, we observe that the strength balance between the Project and a specific stakeholder may change from the “Hub-and-Spoke” Model to the SVN model. For example, in RuSakOil, the most obvious change is the balance between the Project and Host-Country Government, in terms of the “absolute” change reflected by the net transaction value (see Figure 3-24). Meanwhile, if taking the “relative” change reflected by the output/input ratio (i.e., the O/I ratio) as a new criterion, the most obvious change would be the balance between the Project and Local Community (see Figure 3-25). However, for either criterion, these changes signal an advantage gained by other stakeholder via the general exchanges in the network, and this advantage should not be ignored by the focal organization in its strategic decisions regarding stakeholders. This is a very important conclusion in this dissertation and will be validated by the case of Project Phoenix in Chapter 4.

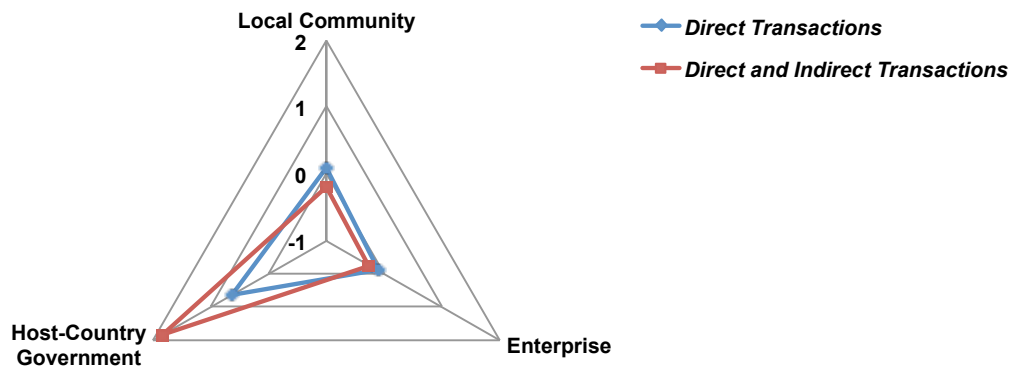


Figure 3-24: Net Transaction Value between the Project and Other Stakeholders

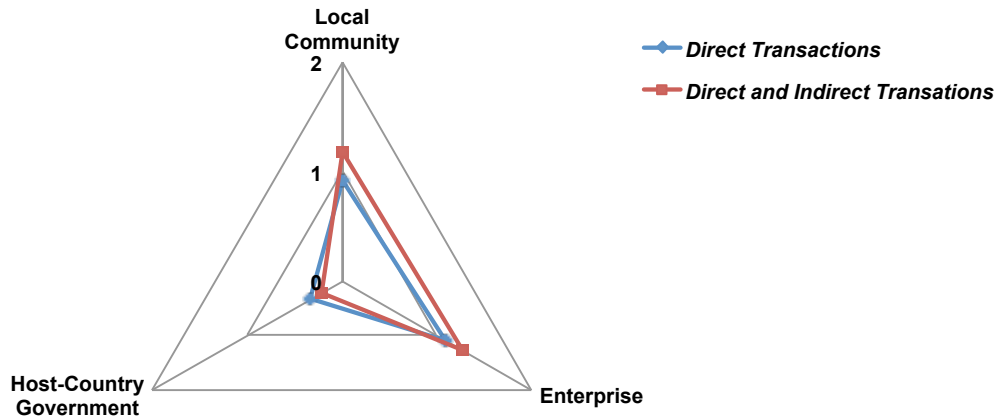


Figure 3-25: O/I Ratio between the Project and Other Stakeholders

3.2.5 Directions for Improvement

After going through the above four steps of “Mapping”, “Quantifying”, “Searching”, and “Analyzing”, the SVN analysis for the RuSakOil (see Figure 3-3) is now completed. Note that these steps can be iterated when more information becomes available for the SVN and/or the situation of previous analysis changes. In addition, the general process and techniques of the SVN analysis (see Figure 3-1) elaborated in this section should be taken as a stand-alone manual with broad applications, rather than the narrow discussion on a specific example.

Before proceeding to the next section, it would be helpful to list a few known limitations of this network approach for stakeholder modeling:

- **Relational Approach:** The essence of the SVN analysis is a relation-based network approach, which treats the exchange relationships as more fundamental phenomena than others in the stakeholder network, and it would be interesting to discover the synergy with other actor- or event- based approaches;
- **Value Propagation:** The SVN analysis takes a multiplicative rule to simplify the calculation of the utility scores of value cycles in the stakeholder network, but

considering these cycles are the basic units for understanding the impacts of indirect stakeholder relationships, it is necessary to develop a more rigorous mathematical model to improve the calculation;

- **Computational Platform:** The Object-Process Network (OPN) is a graphical, domain-neutral, and executable meta-language designed to represent, generate, and manipulate simulation models, but as a computational platform, its capability to handle large networks is seriously constrained, mainly because of the opaque and inefficient algorithms as well as the unnecessary visualization effects;
- **Egocentric Distortion:** Value cycles, the representation of generalized exchanges, are the basic units to measure the impacts of indirect stakeholder relationships in the SVN model, but the sample space of important network statistics is centered on the focal organization and therefore omits those cycles bypassing the focal organization, which may cause distortions of the network structure from a descriptive perspective, as well as of the resulting stakeholder strategies from an instrumental perspective;
- **Strategy Implementation:** Last but not least, the SVN analysis does not provide practical guidelines to effectively implement the derived strategies for stakeholder engagement (for example, how to avoid the problems of moral hazard and free-riding in the generalized exchanges), and these guidelines are much desired in the real world.

Organized by the workflow of the SVN analysis, the above is a list for the known limitations of the methodological framework described in Figure 3-1. Although this is by no means a complete list, one should not be intimidated by the number of those limitations—as wisely commented by Box and Draper [1987, p. 424], “Essentially, all models are wrong, but some are useful.” and “Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful.” [Box and Draper, 1987, p. 74]—articulating these limitations will actually help with the appropriate usage of the SVN approach and also the identification of the directions for further development and improvement.

Specifically, the above five limitations will be addressed one by one in the following sections and chapters (Note that such an arrangement is aligned with the dissertation architecture shown in Figure 1-1):

- *Relational Approach:* In Section 3.3, a conceptual process is proposed to integrate the SVN and Strategic Issue Management; and In Chapter 4, Project Phoenix is taken as an example to demonstrate how to integrate the SVN analysis with the Strategic Issue Management to obtain more insights on stakeholder balance.
- *Value Propagation:* In Section 3.4, a utility model of the generalized exchanges is established to improve the calculation for the scores of value cycles in the stakeholder network; and In Chapter 4, the improved calculations derived from this utility model are applied through the Project Phoenix.
- *Computational Platform:* In Chapter 5, using the technique of the Dependency Structure Matrix (DSM), a more powerful computational platform is developed with the Java language; and In Chapter 6, China's Energy Conservation Campaign is taken as an example to demonstrate the strength of this new platform in dealing with large-size networks.
- *Egocentric Distortion:* In Chapter 5, a new category of network statistics are constructed to interpret the implications of the SVN from the standpoint of the whole network instead of a focal organization; and In Chapter 6, these new statistics are applied to hierarchical modeling for China's Energy Conservation Campaign.
- *Strategy Implementation:* In Chapter 4 and 6, practical guidelines are discussed to implement the stakeholder strategies for a retrospective case (i.e., Project Phoenix) and for a prospective case (i.e., China's Energy Conservation Campaign), respectively.

3.3 Extension A: Integration of Stakeholders and Issues

3.3.1 Rationales behind the Integration

As discussed in Chapter 2, the integration between stakeholders and strategic issues provides a unique research opportunity for this dissertation, and the rationales behind such an integration are mainly three-fold:

- It is **necessary** to have this integration because stakeholder relationships and issue evolutions are delicately intertwined with each other (see Table 2-1): On one hand, stakeholders may be involved in multiple issues [Mahon, Heugens, and Lamertz, 2004], and on the other hand, the interaction of multiple issues may deviate from their normal life cycles because of the awareness of and the influence from stakeholders [Bigelow, Fahey, and Mahon, 1991, 1993]. Bigelow, Fahey, and Mahon [1993] also summarized: “Stakeholders are only mobilized around issues, and issues only emerge when stakeholders advocate them.”
- It is **important** to have this integration because each method has its own strength and weakness: As discussed previously, the concept of “Issues” is currently missing in the framework of the SVN analysis, and such an ignorance causes two major shortcomings—From the analytical perspective, without the consideration of “Issues”, it is difficult to see through the causal mechanisms behind the different stakeholder balance (see Figures 3-22 ~ 3-25) and formulate the corresponding strategies, as once pointed out by Granovetter [1973, p. 1378]: “Treating only the strength of ties ignores, for instance, all the important issues involving their content”; And from the computational perspective, compared to the “Issues”, stakeholder relationships and the types of stakeholder relationships (i.e., Political, Information, Goods/Service, and Financial) are neither a justifiable choice nor a practical principle to restructure the large-size networks so that the modeling complexity can be effectively managed.
- “Relations” are more **fundamental** than “Actors”: Based on the Social Exchange Theory (SET), the attributes of “Actors”, such as Power or Centrality, are actually emerging and evolving in a complex structure of exchanges of resources [Cook, 1990, pp. 115-116], and therefore the “Relations”, especially the exchange relationships, are a more fundamental phenomenon for the network analysis in

social sciences. This is the reason why we propose to integrate the Strategic Issue Management with the SVN analysis, instead of with the Stakeholder Theory directly. As criticized by Rowley [1997], most extant stakeholder research is based on the attributes of stakeholders rather than the relationships among them—we concur with Rowley’s critical comment, and consider this is a questionable exercise of putting the “effect” prior to the “cause”, which even exists in the widely acclaimed theory of Stakeholder Identification and Salience [Mitchell, Agle, and Wood, 1997].

3.3.2 Conceptual Process for the Integration

Based on the above rationales and the limitations of similar proposals, we now conceptualize the following process to integrate the Strategic Issue Management into the four-step framework of the SVN analysis (see Figure 3-1):

- **Issue Identification:** After mapping stakeholders’ specific needs as value flows, the primary issues of concern to different stakeholders can be identified with a specific and appropriate definition of strategic issues in the SVN environment.
- **Stakeholder Re-Identification:** If the number of value flows is much larger than that of strategic issues in the network, and the computational capability of the SVN modeling tool is also challenged, those stakeholders in similar positions (support or opposition) around issues can be grouped together, in addition to the clustering rules of aggregation (role/function) and hierarchy (control/jurisdiction) introduced at the beginning of this chapter.
- **Issue Networks:** Once all the value flows are quantified through the stakeholder questionnaire, the SVN model can be decomposed into several smaller network models organized by the issues identified before, and these smaller network models are also named as “Issue Networks” [Frooman, 2010; Lucea, 2007] in this dissertation. Within each issue network, the modeling complexity is managed because of the smaller number of stakeholders and value flows. Meanwhile, cross these issue networks, the causal mechanism behind different stakeholder balance

can be better understood than in the previous method which analyzes the whole SVN model, or decomposes the SVN model by the type of value flows.

- **Iterative Application:** The above three techniques can be applied in an iterative manner to reduce the dimensionality of large SVN models, until the appropriate level of abstraction is reached with the criteria of both analytical significance and computational feasibility.

Figure 3-26 visualizes the updated methodological framework of the SVN analysis with the above integrative process (see Step 1.5 and 2.5), which will be exercised for and then refined by the case study of Project Phoenix in Chapter 4.

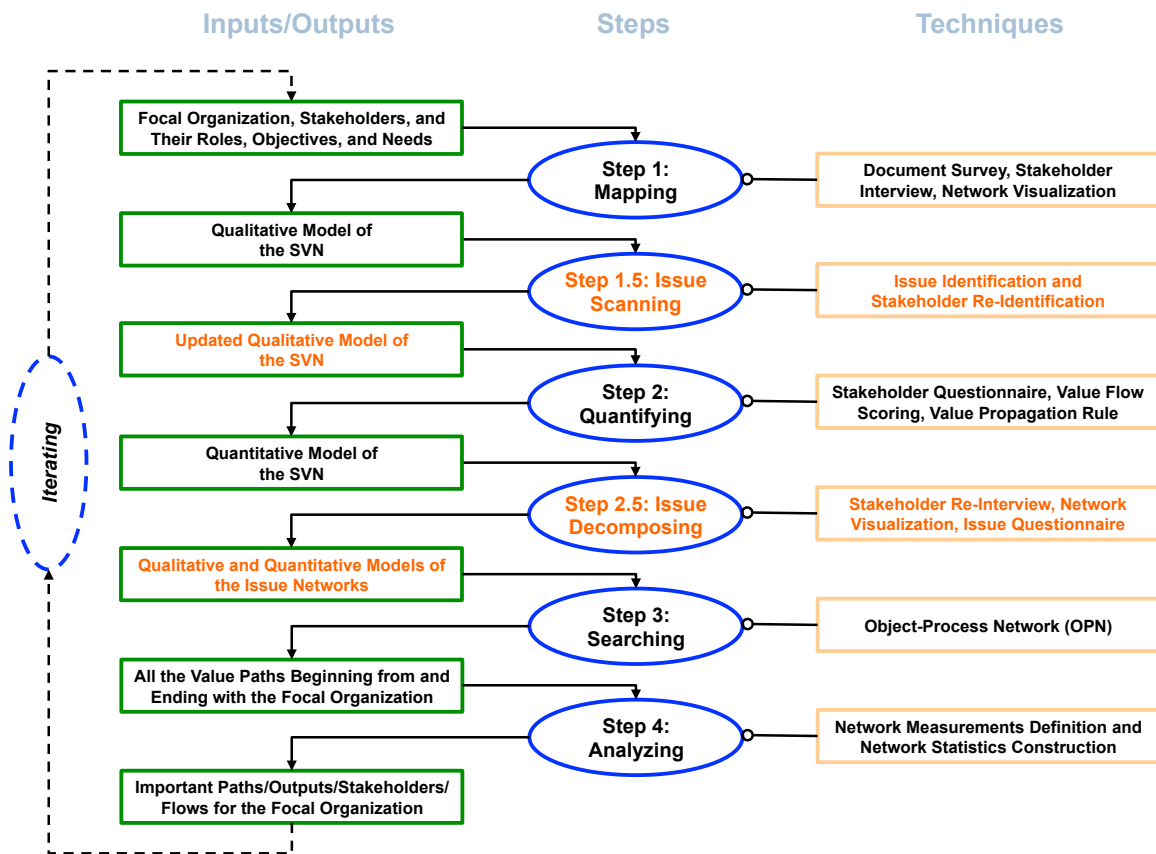


Figure 3-26: Issue-Integrated Framework of the SVN Analysis

3.4 Extension B: Utility Model for Generalized Exchanges

The main goal of this section is to establish a utility model for generalized exchanges in order to derive a “justifiable” and “feasible” mean to calculate the scores of value cycles in the stakeholder network. As introduced in the RuSakOil example, the calculation for the scores of value flows, or the subjective utility of stakeholders’ needs, is firmly based on the Multi-Attribute Utility Theory (MAUT) [Edwards, 1977; Keeney and Raiffa, 1976]. However, the multiplicative rule (see Equation 3-2) used to calculate the scores of value cycles, or the relative importance of generalized exchanges for a focal organization, has not been justified yet, although it is simplified enough and intuitively reasonable, in the sense that the scores of longer cycles are punished to reflect the difficulty of engaging more stakeholders in an indirect way.

This section is divided into two parts: First, a utility model for generalized exchanges is constructed step by step to address the “justifiable” consideration, and the related key assumptions are also discussed. And then, once the model is at hand, an approximation equation for the calculation of value cycle scores is derived to address the “feasible” consideration. In the next chapter, for the Project Phoenix case, this approximation equation will replace the previous multiplicative equation (see Equation 3-2) to calculate the scores of value cycles and improve the results of the SVN analysis. In addition, note that most contents of this section are directly based on a journal article [Cameron, Crawley, Feng, and Lin, 2011] published by the MIT System Architecture Group including the author of this dissertation.

3.4.1 Construction of the Model

First of all, several desired behaviors of this utility model are articulated as below:

- *Non Satiation:* More of an input is always better;
- *Diminishing Marginal Rates of Substitution:* Stakeholders prefer a mix of goods over only one good;

- *Parallel Computation:* The merit of each value cycle can be computed independently of the other cycles through the network;
- *Cost Benefit Tests:* Analysis should indicate which value cycles do not provide the minimum return.

Specifically, the decision behavior of each stakeholder including the focal organization (a.k.a., the reference stakeholder) is modeled using the following four equations (see Equations 3-7 ~ 3-10), illustrated by a simplified two-input problem shown in Figure 3-27. In this sense, we are attempting to bridge the input-output model by Donaldson and Preston [1995] with the SVN model.

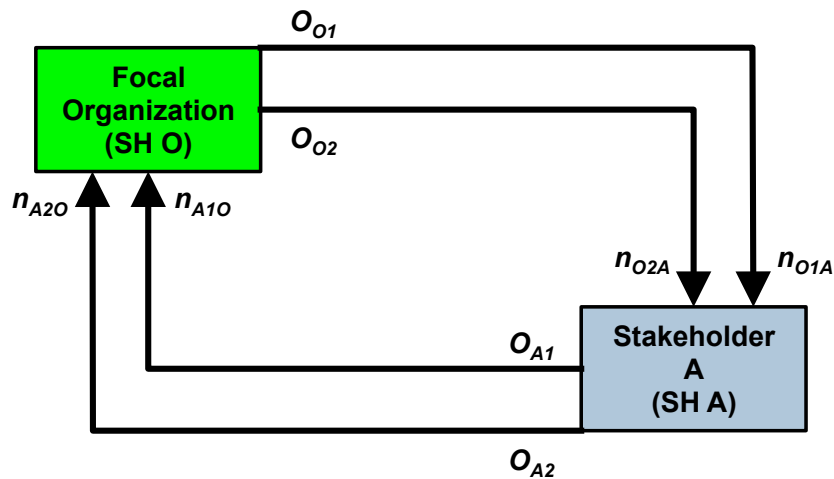


Figure 3-27: Notation for Single Stakeholder Problem

Utility

As defined in Equation 3-7, the utility (U) of each stakeholder is a function of the strength of the Need (n), and the amount of Input (I), where the Input 1 of Stakeholder A is equivalent to the Output 1 of Stakeholder O. Further, it is assumed that the focal organization has a non-linear utility function, and the non-linearity is adjusted by the exponent “ α ”, ranging [0, 1]; while the utility function of its stakeholders is assumed to be linear ($\alpha = 1$), because the non-linear utility of each stakeholder will couple the network together—it will be shown later that linear utility functions for the stakeholders

of the focal organization are sufficient to produce the diminishing marginal rates of substitutions.

$$U_{in} = n_1 I_1^\alpha + n_2 I_2^\alpha \quad \text{(Equation 3-7)}$$

Resources Received

As shown in Equation 3-8, resources (R) are defined as a function of utility (U) to convey that the monetary and nonmonetary outputs produced by the focal organization are sourced from the inputs it receives. The constant “ p ” captures the propensity of the stakeholder to convert its received utility into outputs, in order to avoid the dynamic implications of the accrual of utility stocks because of the static nature of the SVN model. In addition, such a propensity constant may be useful for differentiating among for-profit and non-for-profit stakeholders.

$$R = pU_{out} \quad \text{(Equation 3-8)}$$

Resource Utilization

Outputs are constrained by available resources, and two types of resource models are explored here: In some cases such as material resources, outputs (O_1 and O_2) compete for resources (R) (see Equation 3-9a); In other cases such as information resources, outputs do not compete for resources (see Equation 3-9b)—equivalently, the marginal cost of producing or changing additional units is zero.

$$R = O_1 + O_2 \quad \text{(Equation 3-9a)}$$

$$R = O_1 \ \& \ R = O_2 \quad \text{(Equation 3-9b)}$$

Satisfaction

As shown in Equation 3-10, satisfaction (S) is defined as the generalization of profit and at the equilibrium condition. In addition, S is constrained to be non-negative to reflect the reality that generating profit is the necessary condition to engage a stakeholder into value exchanges.

$$S = U_{in} - U_{out} \geq 0 \quad \text{(Equation 3-10)}$$

In order to demonstrate the solution method for this problem (see Figure 3-27), the outputs in the following exchange will be solved. Interspersed with the solution are modeling decisions made to generate a closed, direct solution.

As it stands, the problem has two objective functions (maximizing the satisfactions of the Focal Organization and Stakeholder A) and six constraints (Equations 3-7 ~ 3-9a for the Focal Organization and Stakeholder A) in four variables (O_{O1} , O_{O2} , O_{A1} , and O_{A2}) with seven constants (n_{A1O} , n_{A2O} , n_{O1A} , n_{O2A} , p_O , p_A , and α). Optimizing for the maximum combined satisfaction of the two players is underdetermined and heavily coupled.

To make the problem solvable, two important assumptions are made below:

- *Egocentric Focal Organization:* The satisfaction of all other stakeholders is constrained to zero, leaving only the focal organization's satisfaction in the objective function. While mathematically convenient, this assumption echoes the rationale for network measurements (i.e., WSO, WOO, WIO, and WVFO) defined in the SVN analysis and also best represents the focal organization's outlook—maximize the long-term profitability of the organization, where the distinction “long-term” is specifically interpreted as retaining stakeholders via non-negative satisfaction, and the word “profitability” represents the non-negative satisfaction and is an extension of the economic profits in traditional sense.
- *Transparent Production Function:* The problem is also decoupled into its constituent value cycles. In order to do so, the input-output mappings must be tracked—for example, the contribution of O_{O1} toward the creation of O_{A1} . This necessarily surfaces the implicit assumptions about the production function of Stakeholder A. In more complex cases it has been found convenient to specify the

input-output mappings, reflecting the fact that not all inputs are simultaneously required to produce each output of the focal organization.

Given the decoupled, constrained cycle problem, each output's contribution to the satisfaction of the focal organization can be analyzed. Conveniently, it can be shown that this system of equations is linear in these contributions, and therefore, superposition can be used to reconstruct the total satisfaction achieved and the desired prioritization of outputs. Substituting Equations 3-7 ~ 3-9a into Equation 3-10, the contribution of O_I to the focal organization's satisfaction is shown as below:

$$(S_o)_{O_I} = n_{A1O} (p_a n_{O1A} O_{O1})^\alpha + n_{A2O} (p_a n_{O1A} O_{O1})^\alpha - \frac{O_{O1}}{p_o} \quad \text{(Equation 3-11)}$$

Given this formulation, weak cycles, in terms of cycle scores, can be pruned. If assuming a unit output and a known value of p_o , it can be computed whether or not the contribution to satisfaction is greater than zero. Cycles not providing positive satisfaction should be excluded from further considerations. This rough cost/benefit calculus effectively reduces the complexity of this model. After pruning, the outputs that maximize satisfaction can be calculated next:

$$O_{O1}^{\max} = (\alpha p_o)^{\frac{1}{1-\alpha}} (n_{A1O} + n_{A2O})^{\frac{1}{1-\alpha}} (p_a n_{O1A})^{\frac{\alpha}{1-\alpha}} \quad \text{(Equation 3-12)}$$

Given the system is symmetrical in O_I and O_2 , the solution for O_{O2} can be inferred, which demonstrates that it is less than the resource constraint.

Figure 3-28 shows the feasible solution space and the optimal allocation of resources for the simplest value exchange, with one flow in either direction. It is observed that the non-linearity in utility at the focal organization (i.e., the firm in the figure) is sufficient to produce an interior solution, consistent with the formulation exhibiting the diminishing marginal rates of substitution among the inputs to the focal organization. Meanwhile, the fully non-linear solution can also be superimposed, to demonstrate the compromise made

by assuming the linear utility of the focal organization's stakeholders. The difference between these two solutions is the errors incurred by requiring computations proceed in parallel.

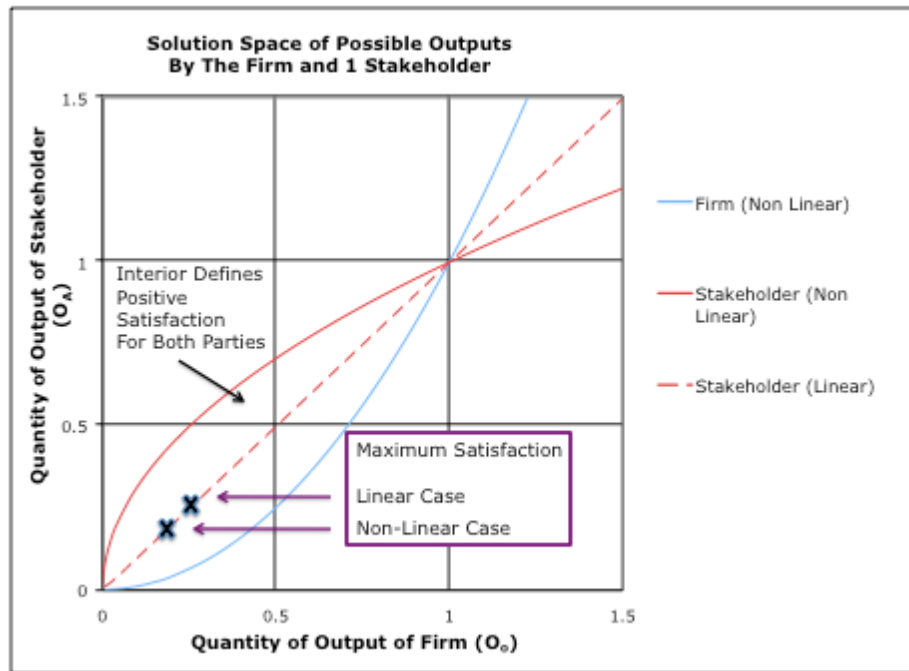


Figure 3-28: Solution Space of Possible Outputs by the Focal Organization and One Stakeholder

In order to illustrate the symmetry of the formulation, the network can be summarized as a Dependency Structure Matrix (DSM, a.k.a., Adjacent Matrix) A . The individual cells of A_{ij} are populated with a summary metric of connection strength for all the value cycles from O_i to I_j . Each A_{ij} , therefore, represents the ability of O_i to influence I_j . Having constructed the matrix A , note that the individual entries are not directly of interest—it is the allocation of outputs of the organization that is important. This breakdown of outputs can be determined by summing across each row of A , which provides a value of the impact potential of each output (see Figure 3-29, where the focal organization is specified as a firm). This sum already incorporates how important the input is to the focal organization. This matrix also provides a methodology for understanding how well the focal organization can expect to influence its inputs. Summing down the columns of A captures all possible paths in the network that lead to that particular input. Recalling the

network measurements defined previously for the RuSakOil, astute readers can immediately find that the sum score of each row is actually the WOO of that output, the sum score of each column is the WIO of that input, and the “Influence Matrix” shown in Figure 3-29 is essentially the same as the “Conversion Matrix” shown in Table 3-7.

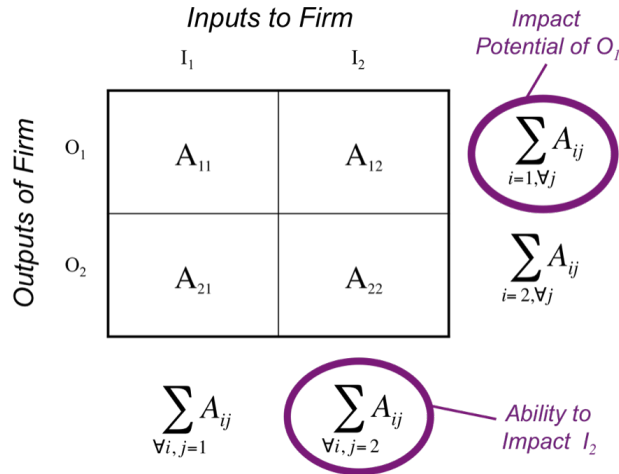


Figure 3-29: Influence Matrix A_{ij}

3.4.2 The Approximation Equation

As a sanity check on the system can be that the distribution of utilities received by the focal organization should correspond to a manager’s intuitive understanding for the relative importance of these inputs. Writing Equation 3-11 in terms of O_{A1} and O_{A2} instead of for O_{O1} , Stakeholder A’s outputs at the satisfaction maximizing solution for O_{O1_max} can be shown as below:

$$(O_{A1}^{\max})_{O1} = (\alpha p_o p_A n_{A1O} n_{O1A})^{\frac{1}{1-\alpha}} \quad \text{(Equation 3-13a)}$$

$$(O_{A1}^{\max})_{O2} = (\alpha p_o p_A n_{A1O} n_{O2A})^{\frac{1}{1-\alpha}} \quad \text{(Equation 3-13b)}$$

$$(O_{A1}^{\max}) = (O_{A1}^{\max})_{O1} + (O_{A1}^{\max})_{O2} = (\alpha p_o p_A n_{A1O})^{\frac{1}{1-\alpha}} (n_{O1A}^{1-\alpha} + n_{O2A}^{1-\alpha}) \quad \text{(Equation 3-13c)}$$

If the same process is followed to generate for O_{O2_max} , their ratio can be calculated in Equation 3-14:

$$\frac{O_{A1}^{\max}}{O_{A2}^{\max}} = \frac{(n_{A1O})^{\frac{1}{1-\alpha}}}{(n_{A2O})^{\frac{1}{1-\alpha}}} \quad \text{(Equation 3-14)}$$

Substituting Equation 3-14 into Equation 3-7, and taking the ratio of the instantiations for A_1 and A_2 , Equation 3-15 can be obtained:

$$\frac{U_{A1}}{(n_{A1O})^{\frac{1}{1-\alpha}}} = \frac{U_{A2}}{(n_{A2O})^{\frac{1}{1-\alpha}}} \quad \text{(Equation 3-15)}$$

Having solved a simplified case, it is easy to extrapolate the solution with n vertices (stakeholders) along a value cycle (generalized exchange). For each cycle through the network with Stakeholder A, B, ..., Z, starting with O_{O1} , the contribution to that Output's importance can be shown in Equation 3-16:

$$O_{O1}^{\text{cycle1}} = (\alpha p_o)^{\frac{1}{1-\alpha}} (n_{Z1O})^{\frac{1}{1-\alpha}} (p_a p_b \dots p_z n_{O1A} n_{A1B} \dots n_{Y1Z})^{\frac{\alpha}{1-\alpha}} \quad \text{(Equation 3-16)}$$

The above equation is a very important result in this dissertation, and actually, it is the right answer for which this section has searched. Derived from the utility model of generalized exchanges constructed here, Equation 3-16 provides a justifiable way to quantify the relative importance of value cycles, which are then taken as the basic units to interpret the impacts of indirect stakeholder relationships, from the perspective of a focal organization.

Specifically, when $\alpha = 0.5$, Equation 3-16 changes into a concise format:

$$O_{O1}^{\text{cycle1}} = (0.25 p_o^2 p_a p_b \dots p_z) (n_{O1A} n_{A1B} \dots n_{Y1Z}) (n_{Z1O})^2 \quad \text{(Equation 3-17)}$$

Deleting the constant items from Equation 3-17, the desired approximation equation for the calculation of value cycle scores is finally written as:

$$O_{O1}^{cycle1} = (n_{O1A}n_{A1B} \dots n_{Y1Z})(n_{Z1O})^2 \quad \text{(Equation 3-18)}$$

It is observed that Equation 3-18 is amazingly similar to the multiplicative equation (see Equation 3-2) chosen before, except that the utility score of the last value flow in the cycle, or the input flow to the focal organization, is multiplied twice instead of once. Based on the fact that the input value flows are the graphical representation for the specific needs of the focal organization, we argue there can be a profound implication behind the minor difference between Equation 3-18 and Equation 3-2—by multiplying the utility score of the last value flow one more time, it reflects the discrimination of the focal organization against other value flows than the last one which satisfies the focal organization’s own needs—on one hand, this discrimination exactly reflects the egocentric assumption stated before; on the other hand, this discrimination can also lead to distortions on interpreting the exchange and structure properties of other stakeholders in the network, which is the limitation of “Egocentric Distortion” listed in the end of last section. Another way easier for scientists and engineers to understand this minor difference, we suggest, is to take the one more multiplication of the last value flow as the “transformation coefficient” from a fairness-based value system to an egocentric value system, just like the “transformation coefficient” between different coordination systems in mathematics and physics.

Finally, for the convenience of quotation, we name Equation 3-2 as the “*abc*” rule hereafter, while by contrast, we name Equation 3-18 as the “*abc*²” rule, which will be applied to calculate the value cycle scores in the Project Phoenix case in Chapter 4.

3.5 Chapter Summary

Organized into three major sections, this chapter mainly develops the methodological framework for analyzing the SVN from the perspective of a focal organization: First of all, a four-step modeling framework for the SVN analysis is elaborated in detail step by step, with a simplified multinational energy project as the running example; Second, responding to the limitations of this basic framework, two important extensions are proposed.

The first proposed extension is the integration of Strategic Issue Management with the SVN analysis, in order to reveal additional insights into the strength balance between stakeholders, as well as to manage the complexity of the network models for the computational feasibility. The second extension is the construction of a utility model of generalized exchanges to help derive a justifiable and feasible method to calculate the scores of value cycles, which are taken as the basic units for understanding the impacts of indirect stakeholder relationships in the SVN.

Next, in Chapter 4, the four-step modeling framework along with the above two extensions will be applied to analyze the SVN of a large real-world engineering project, that is, Project Phoenix. In return, the results from this retrospective case study will be used to validate the strength of the framework discussed in this chapter. Combining these two chapters together, the first module of the main body of this dissertation is complete (see Figure 1-1), and one is ready to conduct the SVN analysis from the perspective of a focal organization.

CHAPTER 4. CASE STUDY I: PROJECT PHOENIX

“Fifty years ago, the main challenges to large infrastructure projects were technical or scientific. Today, the greatest hurdles faced by such projects are almost always social and / or political.”

— McAdam, Boudet, Davis, et al. [2010, p. 401]

4.1 Chapter Introduction

In this chapter we apply the SVN framework previously illustrated in Chapter 3 to Project Phoenix, a large real-world engineering project. By comparing the most important stakeholders derived from Managers’ Mental Model with those identified by the WSO (Exchange Centrality) in the “Hub-and-Spoke” and “Network” (SVN) models, we successfully demonstrate the strength of the SVN analysis, especially in understanding the impacts of indirect stakeholder relationships from the perspective of a focal organization.

The SVN Model we apply in this chapter incorporates two major extensions to the simplified RuSakOil example of Chapter 3 that together improve both the descriptive accuracy and instrumental power of the SVN analysis, especially on the balance of stakeholder relationships emerging from the network of value exchanges. First, we integrate an alternative way of mapping an organization’s “institutional fields” [Dimaggio and Powell, 1983; North, 1990, 1991; Scott, 1987, 2002, 2005], the Strategic Issue Management [Ansoff, 1980; Arcelus and Schaeffer, 1982; Bartha, 1983; Bigelow, Fahey, and Mahon, 1991, 1993; Chase, 1982, 1984; Dutton and Duncan, 1987; Johnson, 1983; Mahon and Waddock, 1992] through the concept of “Issue Networks” [Frooman, 2010; Lucea, 2007; Lucea and Doh, 2012]. Second, we incorporate a new rule for value propagation to calculate the scores of value cycles for the focal organization, including

the value cycle scores in those newly developed “Issue Networks”. This “ abc^2 ” rule, obtained from a rigorous utility model of Generalized Exchanges [Cameron, Crawley, Feng, and Lin, 2011], replaces the multiplicative “ abc ” rule we used earlier.

4.2 Case Description and Project Phoenix Managers’ Mental Model

Project Phoenix is a major “brownfield project” being implemented by a Global 500 firm in one of its older operating facilities in the United States. It is integrated into a complex processing facility that is undergoing a change in the mix of feedstocks and chemical products. Many of these new feedstocks come from an adjacent country. In the early 2000s, the focal firm announced Project Phoenix, to expand the unit’s production capacity and equip it to deal with a new mix of feedstocks and chemical products. At the time of the announcement, the project was expected to require a multi-billion dollar investment and five years to complete.

In the first year of the project, the firm successfully obtained new environmental permits from the host state’s Environmental Protection Agency (EPA). The new permits allow the facility to increase the emission levels of certain chemicals. Even though the increased levels still comply with EPA environmental standards, this situation ignited a firestorm of protest in the public media and from local public from surrounding communities that had not been anticipated by Project Phoenix’s managers. After a several-month negotiation, the owner finally promised to keep the original emission levels and admitted that they might be forced to cancel Project Phoenix as a result.

Although subsequently the Project Phoenix’s managers found that the Project could be completed within the original discharge limits and

actually also proceeded with it, significant delay and escalation of cost have been made to the project. The analysis of this case study focuses on the initial period ending with the strong public pushback.



Figure 4-1: Project Phoenix Production Process (viz., Goods/Service Flows)

From the above introduction, which is based on the public information, it is reasonable to infer that before experiencing the unexpected protest, the most important stakeholders in Project Phoenix Managers' Mental Model were the Host State Government and the U.S. Federal Government. We confirmed this observation through multiple rounds of interviews with Project Phoenix's managers. Managers had not paid enough attention to the Public Media and the Local Public, and this resulted in significant delay and increased cost to the project as well as serious damage to the image of the project's owner later on.

Following Denzau and North [1994, p. 4], we define the "mental model" as the "internal representations that individual cognitive systems create to interpret the environment", because "cognitive systems construct models of the problem space that are then mentally 'run' or manipulated to produce expectations about the environment" [Holland et al., 1986, p. 12]. Further, under conditions of uncertainty, "individuals with common culture backgrounds and experiences will share reasonably convergent mental models" [Denzau and North, 1994, p. 3], and we found that the above mental model had been widely shared by Project Phoenix's managers before they saw the firestorm of protest in 2007.

Note that the time window of this case study has been narrowed down to 2006~2007, during which Project Phoenix was announced and then met unexpected protest from the Public Media and the Local Public. In other words, this is a "retrospective" case study. As discussed in Chapter 3, the SVN Model is essentially one static "snapshot" of the value exchanges between stakeholders at a specific temporal stage. As a result, the main

purpose of the SVN analysis in this chapter is to explore the reasons why the Public Media and the Local Public were missed in the short list of the most important stakeholders in Project Phoenix Managers' Mental Model, rather than to formulate effective strategies for managing the relationships with those stakeholders¹⁶. Using Donaldson and Preston's [1995, p. 65] terminology, the SVN analysis in this chapter is more "descriptive" than "instrumental".

In addition, because the case study of the Project Phoenix is a retrospective one, it was very important for us to remind all the stakeholder representatives that they should not apply their "later" experience (viz., after seeing the protest from the Public Media and Local Public) in answering the stakeholder questionnaire for value flow scoring in the second step of the SVN analysis (see Figure 3-1). Such experience will become the "noise" clouding the process to discover the reasons behind the absence of two important stakeholders (viz., Public Media and Local Public) in the Managers' Mental Model.

With this "prior" information for the Project Phoenix, we constructed a "Network" Model consisting of stakeholders and their exchange relationships within the framework of the SVN analysis. We also constructed a traditional "Hub-and-Spoke" Model by examining only the direct and bilateral value exchanges (viz., pairs of value flows, or "restricted exchanges") between Project Phoenix and its stakeholders. Using the WSO statistic defined in Chapter 3, we then extracted two short lists of the most important stakeholders for Project Phoenix (viz., the focal organization) from the "Network" and "Hub-and-Spoke" models respectively and compared them with the Managers' Mental Model.

4.3 The SVN Analysis and Comparisons of Three Models

In Chapter 3, the methodological framework of the SVN analysis is decomposed into four major steps—"Mapping", "Quantifying", "Searching", and "Analyzing" (see Figure 3-1).

¹⁶ In Chapter 6 we develop a normative analysis on a "prospective" case study of China's Energy Conservation Campaign.

Since the general purpose and techniques of each step are elaborated in detail in the context of the RuSakOil case of Chapter 3, we only presents the key results of each step in the case study of Project Phoenix, with necessary discussion on practice cautions and method variations. Specifically, in the last step, the SVN analysis for the Project Phoenix case culminates with the comparison of important stakeholders between three models, that is, Managers' Mental Model, the "Hub-and-Spoke" Model, and the "Network" Model, to demonstrate the strength of the SVN approach in understanding the impacts of indirect stakeholder relationships, especially from the perspective of a focal organization.

4.3.1 Step One: Mapping

We utilize publically available information collected from news, reports, websites, stakeholder policy and strategy documents, as well as the multi-round interviews with Project Phoenix's managers at the operating facility, to identify a manageable list of stakeholders. In Chapter 3, three methods [Calvert, 1995; Cleland, 1998; Crawley, 2009; Mitchell, Agle, and Wood, 1997; Winch, 2004] are introduced and then combined as a practical guidance for stakeholder identification. Table 4-1 summarizes the relationships between each identification method and the stakeholder list for Project Phoenix. For the convenience of discussion, we will typical refer to these 14 stakeholders by their acronyms.

Next, with the help of the stakeholder characterization template introduced in Chapter 3, each stakeholder's roles, objectives, and specific needs are clearly articulated step by step. Figure 4-2 takes the Local Governments (LOG) as an example to illustrate again the application of such a template. Based on these templates, the specific needs of stakeholders are mapped as four types of value flows (viz., political, information, goods/service, and financial flows, see Figure 3-7) running into them, which together constitute the qualitative SVN Model.

Table 4-1: Stakeholder Identification for Project Phoenix

Stakeholder (Abbreviation)	Identification Approach		
	<i>Crawley [2009]</i>	<i>Calvert [1995], Cleland [1998], Winch [2004]</i>	<i>Mitchell, Agle, and Wood [1997]</i>
Local Governments (LOG)	Institutions	External/Public; Nonmarket	Expectant Stakeholder
Host State Government (HSG)	Institutions	External/Public; Nonmarket	Definitive Stakeholder
Adjacent State Representatives (ASR)	Interests	External/Public; Nonmarket	Latent Stakeholder
U.S. Federal Government (UFG)	Institutions	External/Public; Nonmarket	Definitive Stakeholder
Feedstock Country Government (FCG)	Beneficiaries	External/Public; Nonmarket	Latent Stakeholder
Feedstock Country Transportation (FCT)	“Stake” Holders	Internal/Supply; Market	Definitive Stakeholder
Feedstock Country Producers (FCP)	“Stake” Holders	Internal/Supply; Market	Definitive Stakeholder
New Tech Generators (NTG)	“Stake” Holders	Internal/Supply; Market	Expectant Stakeholder
Contractors/Suppliers/3 rd Parties (CSP)	“Stake” Holders	Internal/Supply; Market	Expectant Stakeholder
Local Public (LOP)	Users	Internal/Demand; Market	Expectant Stakeholder
Public Media (PUM)	Interests	External/Private; Nonmarket	Expectant Stakeholder
NGO (NGO)	Interests	External/Private; Nonmarket	Expectant Stakeholder
International Finance (INF)	“Stake” Holders	Internal/Demand; Market	Definitive Stakeholder
Project Phoenix (PP)	The Focal Organization		

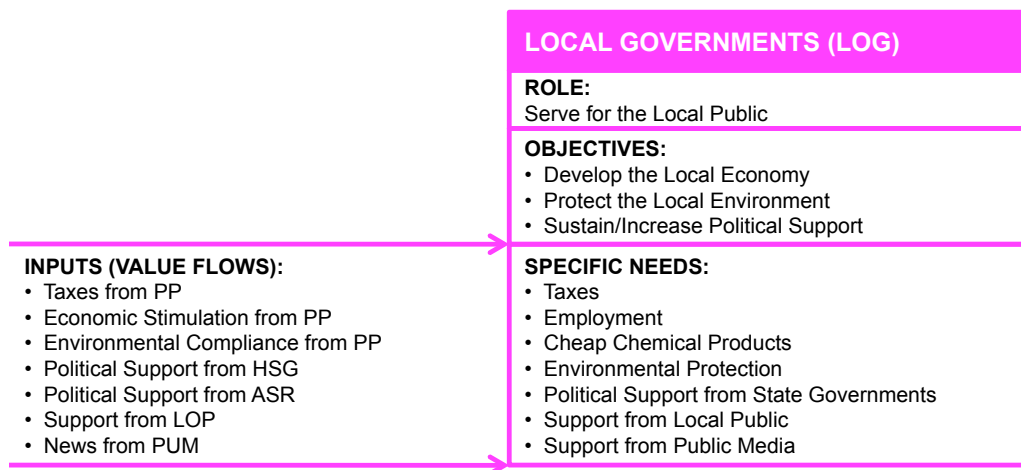


Figure 4-2: Stakeholder Characterization Template for Local Governments (LOG)

For the Project Phoenix case, Figure 4-3 visualizes the qualitative SVN Model in the format of stakeholder map, which includes 14 stakeholders and 74 value flows in total. Note that the SVN Model of the Project Phoenix case is much larger than the one of the RuSakOil case, which included only 9 stakeholders and 27 flows. In addition, for the Project Phoenix case, on average each stakeholder has five value flows.

The resulting stakeholder map is decomposed into different views by the types of value flows: Figure 4-4 presents the political flows, Figure 4-5 presents the information flows, Figure 4-6 presents the goods/service flows, and Figure 4-7 presents the financial flows.

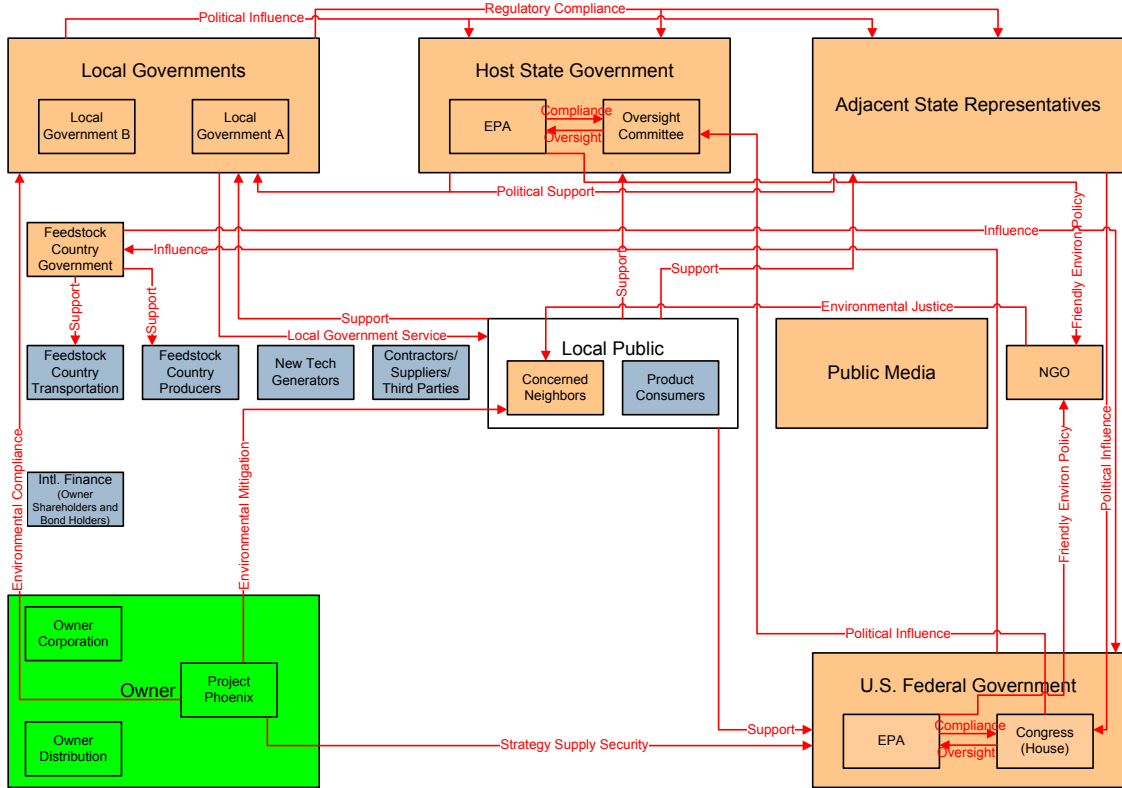


Figure 4-4: Political Flows in the Stakeholder Map

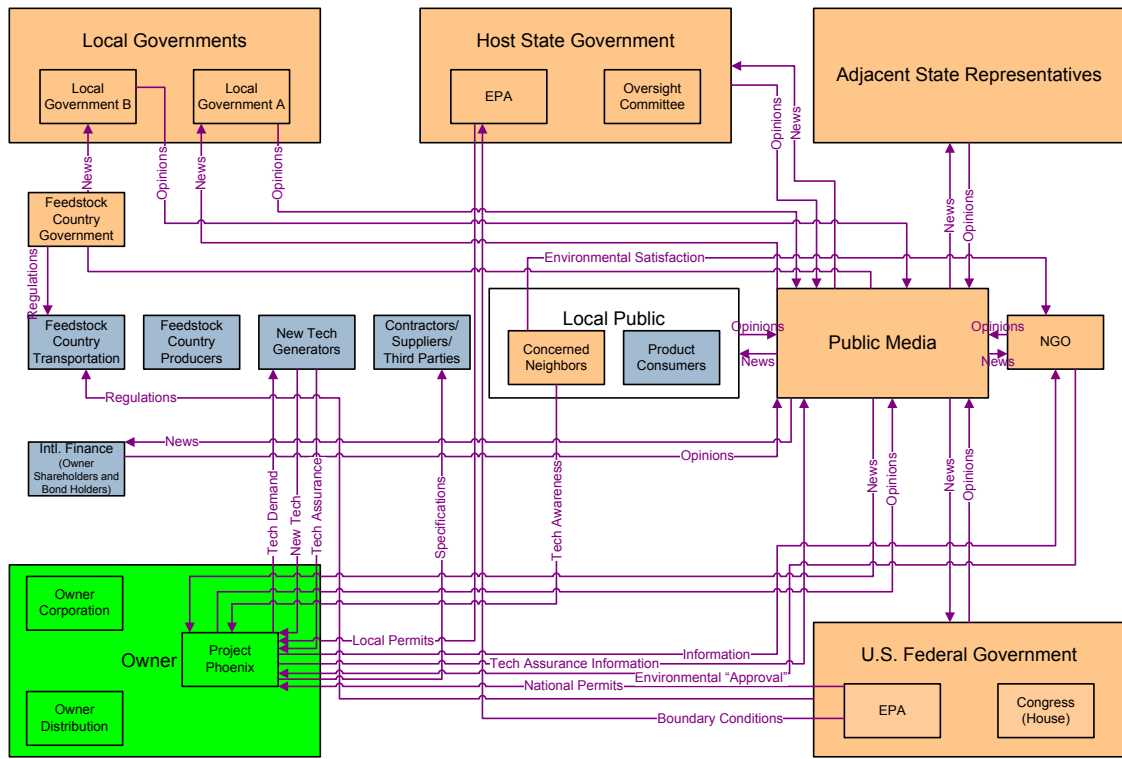


Figure 4-5: Information Flow in the Stakeholder Map

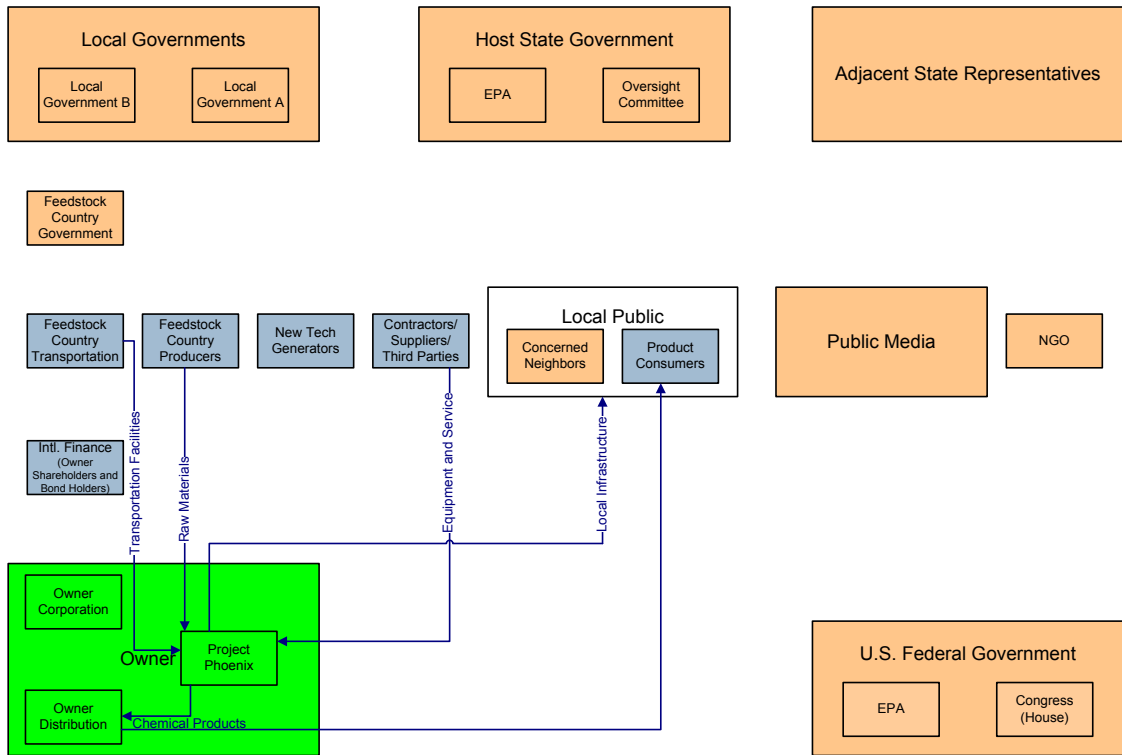


Figure 4-6: Goods/Service Flows in the Stakeholder Map

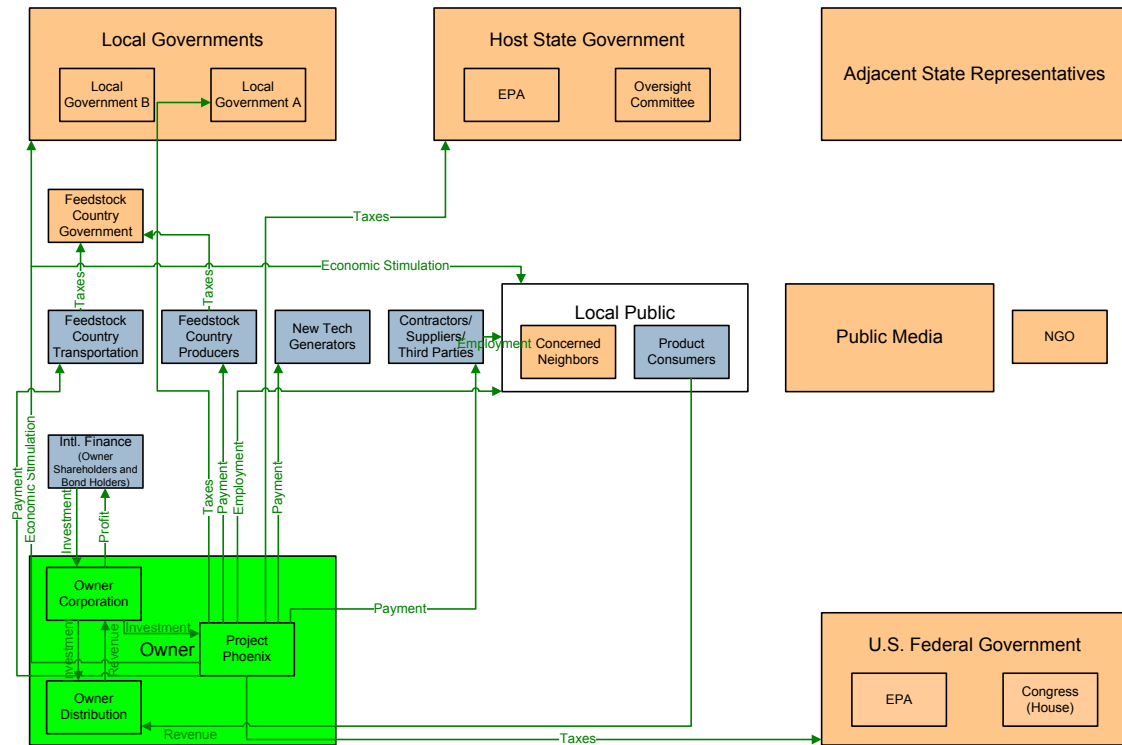


Figure 4-7: Financial Flows in the Stakeholder Map

In addition to the process of stakeholder identification and value flow definition, which is discussed in detail in Chapter 3 (see Sections 3.2.1.1 and 3.2.1.2), there are four more topics that require further development in order to better map the SVN in practice. These topics are *Organizational Hierarchy within Stakeholders*, *Accompanying Documents for Value Flows*, *Visualized Insights from Stakeholder Maps*, and from “Hub-and-Spoke” to “Network”:

4.3.1.1 Organizational Hierarchy within Stakeholders

From the stakeholder map shown in Figure 4-3, it is apparent that Project Phoenix (PP), Local Governments (LOG), Host State Government (HSG), U.S. Federal Government (UFG), and Local Public (LOP) consist of several “smaller” stakeholders: PP includes the Owner Corporation, Owner Distribution, and Project Phoenix, which the operating facility belongs to; LOG includes the Local Government A and the Local Government B; HSG includes the Environmental Protection Agency (EPA) on the state level and its Oversight Committee; UFG includes the Environmental Protection Agency (EPA) on the national level and the U.S. Congress, where the House of Representatives is mainly involved in this case; and LOP includes the Concerned Neighbors and Chemical Product Consumers, which can be the same group of local people when they focus their attention on the needs for different things, that is, clean environment and/or cheap chemical products.

The main reason for the inclusion of multi-level organizational hierarchy for the above five stakeholder—PP, LOG, HSG, UFG, and LOP—lies in the factor that these large organizations or groups play a broad range of roles leading to many different needs. As a result, it is necessary to understand their internal structures before their specific needs for value exchanges can be fully identified. For example, within the LOG, Local Government B may have different opinions on the project than Local Government A, because the additional taxes from this project only go to the latter (see Figures 4-3 and 4-7) according to state laws and regulations, but the increased pollution will impact the natural environment near both governments, perhaps in different ways and different

extents. In addition, we find that in the real world, it is not uncommon for researchers and practitioners to come up with a long list of stakeholders on various organizational levels at the beginning, and then gradually understand the hierarchical relationships between these stakeholders.

In the subsequent analysis, however, the organizational structures of the above five stakeholders are hidden mainly because of limitations of computational and/or analytical resources, especially on the current modeling platform, that is, the Object-Process Network (OPN) [Koo, 2005]. Specifically, the stakeholders in a particular jurisdictional hierarchy will be clustered together to shorten the long list of stakeholders into a manageable one usually including less than twenty¹⁷ stakeholders.

In Chapter 5, a more powerful modeling platform is developed and new statistical measurements are constructed for the whole network analysis, making it possible to model the multiple hierarchies of large stakeholders in terms of the requirements from both computational and analytical aspects. Consequently, we are able to explore the principles for hierarchical modeling to advance the SVN analysis to the next level and will also apply these principles into the case study of China's Energy Conservation Campaign in Chapter 6.

4.3.1.2 Accompanying Documents for Value Flows

The second important topic is the accompanying documents for more detailed definitions of value flows. After many practical applications of the SVN analysis [Cameron, 2007; Seher, 2009; Sutherland, 2009], we observe that the stakeholder characterization templates (see Figures 3-2 and 4-2) are not enough to define the value flows precisely, and therefore different interpretations for the same value flows may exist between researchers and stakeholder representatives. As a result, the accuracy and credibility of

¹⁷ As discussed in Chapter 3, this number represents a “rule of thumb” based on all the existing SVN work in our research group during the past six years, and it should be able to go up with more computational and analytical resources.

the SVN analysis will be negatively impacted, which makes it necessary to have these accompanying documents.

Table A-4-1 in the Appendix shows an example of the accompanying documents for the 74 value flows in the Project Phoenix case. In general, it is important to define the providing and recipient stakeholders, as well as the spatial, temporal, and economic/social contexts of each flow, and also clarify a few places easily leading to various interpretations. More importantly, considering the iterative nature of the SVN analysis, these accompanying documents for value flows should be continuously updated when more information becomes available and/or the situations for previous analysis have changed, so that the SVN analysis can serve as a common platform for engineering, external affairs, commercial, and management within a large engineering project to communicate important information about stakeholders. In addition, these documents will help researchers and stakeholder representatives surface the implicit assumptions and share the same understanding before they answer the stakeholder questionnaires to better quantify the value flows in the second step of the SVN analysis.

4.3.1.3 Visualized Insights from Stakeholder Maps

As demonstrated by the popular work of Tufte [1983, 1990, 1997], visualization can be a powerful tool generating insights from non-graphic information, and this is also the main purpose for the SVN analysis to visualize the qualitative SVN models as “stakeholder maps” before proceeding to build the quantitative SVN models.

In particular, as discussed in Chapter 3, the SVN analysis has designed a color-coding system (see Figure 3-3) to show different types of stakeholders and value flows in the stakeholder maps: For stakeholders, the focal organization is colored with light green, the market stakeholders are colored with light blue, and the nonmarket stakeholders are colored with light salmon; For value flows, red color represents the political flows, purple color represents the information flows, blue color represents the goods/service flows, and green color represents the financial flows. Such a color-coding system is based on the

theories of nonmarket strategy [Baron, 1995] and resource exchange [Foa and Foa, 1971, 1974, 1980], and aims to discover the connections between the types of value flows and the environment where they are exchanged, as well as other possible principles or patterns for the value exchanges in the stakeholder network.

Moreover, in order to increase the visibility of large SVN models which include lots of stakeholders and value flows, stakeholder maps can be decomposed into multiple views according to different criteria, such as value flow types and project temporal stages. For the Project Phoenix case, Figures 4-4 ~ 4-7 show the decomposition of the stakeholder map (see Figure 4-3) by four types of value flows, that is, political, information, goods/service, and financial flows. Together with the above color-coding system, two interesting observations for these four figures are made as below:

First, the political and information flows (colored in red and purple, respectively) are mainly between nonmarket stakeholders (colored in light salmon) and therefore are mediated by the nonmarket environment, while the goods/service and financial flows (colored in blue and green, respectively) are mainly between market stakeholders (colored in light blue) and therefore are mediated by the market environment. This observation is consistent with Baron's definitions for the market and nonmarket environments [1995].

Second, the density of political and information flows (colored in red and purple, respectively) is much larger than that of goods/service and financial flows (colored in blue and green, respectively). Beautifully echoed in the recent findings of social movements scholars [McAdam, Boudet, Davis, et al., 2010, p. 401]: "Fifty years ago, the main challenges to large infrastructure projects were technical or scientific. Today, the greatest hurdles faced by such projects are almost always social and/or political", this simple observation is actually quite meaningful with regard to its close connection to the Social Exchange Theory (SET) [Cropanzano and Mitchell, 2005; Zafirovski, 2005] and will be discussed again when exploring the fundamental reasons for the different results from three stakeholder models (viz., Project Phoenix Managers' Mental Model, the

traditional “Hub-and-Spoke” Model, and the “Network” (SVN) Model) in the last step of the SVN analysis for the Project Phoenix case.

4.3.1.4 From “Hub-and-Spoke” to “Network”

As discussed in Chapter 2, based on the existing management literature, we identify five different stages for the development of the models for modern firms, from the earliest to the latest (see Figures 2-3 ~ 2-7, respectively): the Production Model, the Managerial Model, the Stakeholder Model, the Single-Relational Network Model, and the Multi-Relational Network Model.

In order to validate the strength of the SVN analysis on understanding the strategic implications of the indirect stakeholder relationships, three different models will be compared in terms of their capability of identifying the most important stakeholders for the focal organization. These three models, namely, Project Phoenix Managers’ Mental Model, the “Hub-and-Spoke” Model, and the “Network” Model, actually corresponds to the Managerial Model, the Stakeholder Model, and the Multi-Relational Network Model in the above discussion, respectively.

Because Project Phoenix Managers’ Mental Model and the “Network” Model have already been built up through publically available information and multi-round interviews in the first step of the SVN analysis, it is not necessary starting from scratch to build the “Hub-and-Spoke” Model for the Project Phoenix. Instead, a reverse and simplified approach is taken to deduce the “Hub-and-Spoke” Model from the existing “Network” Model (see Figure 4-3), by only including the direct relationships between the focal organization and its stakeholders while excluding those indirect relationships as well as the relationships between the focal organization’s stakeholders. The resulting model is shown in Figure 4-8.

the previous RuSakOil case (see Figure 3-9), to combine the scores of these two attributes in stakeholder questionnaire into a single utility score for each value flow with the theoretical support from the Multi-Attribute Utility Theory (MAUT) [Edwards, 1977; Keeney and Raiffa, 1976], as introduced in Chapter 3.

Need Urgency Questionnaire

How would you characterize the urgency of fulfillment of this need?

- A. It can be fulfilled after four years from now
- B. It should be fulfilled between the third and fourth year from now
- C. It should be fulfilled between the second and third year from now
- D. It must be fulfilled next year
- E. It must be fulfilled this year

Figure 4-9: Stakeholder Questionnaire for Categorizing the Urgency in Fulfilling a Need

Source Importance Questionnaire

If this need were to be fulfilled, how important would this specific source be in fulfilling the need?

- 1. Not important – I do not need this source to fulfill this need
- 2. Somewhat important – It is acceptable that this source fulfills this need
- 3. Important – It is preferable that this source fulfills this need
- 4. Very important – It is strongly desirable that this source fulfills this need
- 5. Extremely important – It is indispensable that this source fulfills this need

Figure 4-10: Stakeholder Questionnaire for Categorizing the Source Importance in Fulfilling a Need

Source Importance Score	5 = 0.98	0.11	0.22	0.32	0.65	0.96
	4 = 0.78	0.09	0.17	0.26	0.51	0.76
	3 = 0.55	0.06	0.12	0.18	0.36	0.54
	2 = 0.33	0.04	0.07	0.11	0.22	0.32
	1 = 0.11	0.01	0.02	0.04	0.07	0.11
		A = 0.11	B = 0.22	C = 0.33	D = 0.66	E = 0.98
Need Urgency Score						

Figure 4-11: Combination Rule of Value Flow Attribute Scores

Note that in Figure 4-11, the scale for the Need Urgency Score is designed to be nonlinear to meet the common assumption in economics for human’s choice over time [Edwards, 1954; Koopmans, Diamond, and Williamson, 1964; Samuelson, 1937], that is, the value of the later rewards tends to be discounted by a factor (viz., “discount factor” or DF) that increases with the length of the delay (with or without uncertainty).

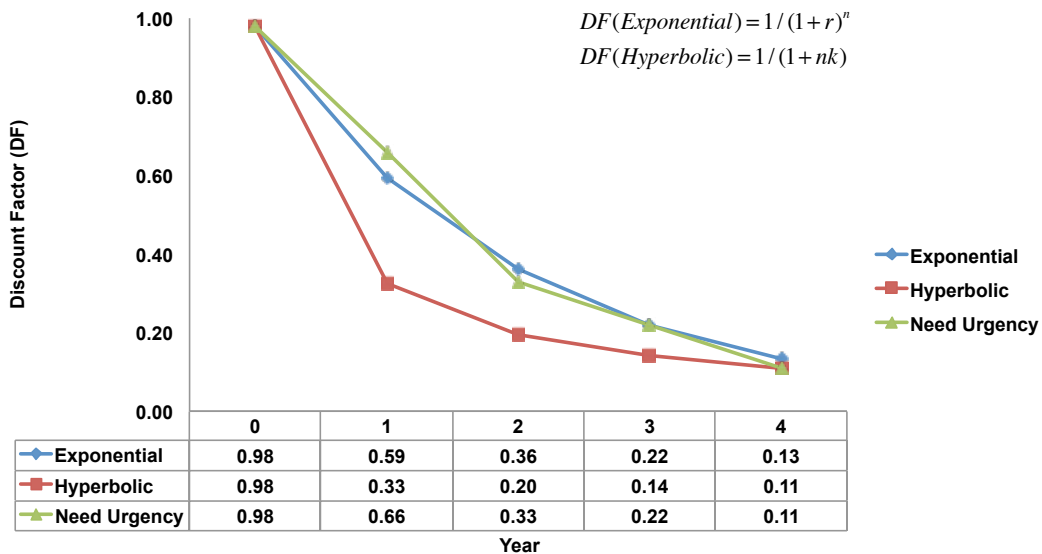


Figure 4-12: Comparison of Three Time Discounting Scales

Further, Figure 4-12 compares the scale of the Need Urgency Score with the exponential and hyperbolic discounting scales, which have seen broad applications in economic models [Frederick, Loewenstein, and O'Donoghue, 2002]. A few important observations for Figure 4-12 are made as below:

- The scale of the Need Urgency Score is closely aligned with the exponential discounting scale, which is a more traditional choice than the hyperbolic discounting scale. However, as pointed out by Frederick, Loewenstein, and O'Donoghue [2002] among other literature, a large number of empirical studies have demonstrated that the constant “discount rate” (r) in exponential discounting is systematically being violated, and hyperbolic discounting is a mathematical improvement over exponential discounting and has been observed in the behavior of humans and animals [Laibson, 1997]. Therefore it could be interesting to apply the hyperbolic discounting in future research.
- Based on calculations, the annual discount rate of the exponential discounting scale approximately equals 65%, which is at the high end of the normal range of annual discount rates in economic models [Frederick, Loewenstein, and O'Donoghue, 2002, p. 379]. However, this choice may be justified by one of the three key assumptions for the SVN analysis (viz., the first assumption of “Relationship Types”, see Chapters 2 and 3) that not only monetary value but also nonmonetary value is exchanged within the stakeholder networks. Moreover, for Project Phoenix, timing is an especially important consideration and any delay related to the project will significantly decrease the perceived utility levels of the focal organization and its stakeholders.
- Astute readers may find that one year is chosen as the basic unit for the scale of Urgency Need Score, but for those 74 value flows in the Project Phoenix case (see Figure 4-3), some of them will certainly span for more than one year, which means the stakeholder representatives may check two or more blocks when answering the columns of “URGENCY OF NEED” in the questionnaire (see Table A-4-2 in the Appendix). For simplicity, if this situation occurs, we will

only take the highest utility score for that value flow, instead of converting several scores into one not included in Figure 4-11.

Once the method for value flow scoring is chosen and the propagation rule of value flows is defined, the remaining task for the construction of the quantitative SVN Model is to distribute the stakeholder questionnaire (see Table A-4-2 in the Appendix) to all the representatives of each stakeholder and then collect the converged answers from them through multi-round interviews as well as the Delphi approach [Brown, 1968; Dalkey and Helmer, 1963; Linstone and Turoff, 1975; Sackman, 1974]. Detailed discussion on the stakeholder questionnaire has been provided in Chapter 3 (see Section 3.2.2.1), and specifically, for the retrospective case of Project Phoenix, one additional caution is to remind the stakeholder representatives to not apply their later experience into their answers to the questionnaire, as highlighted at the beginning of this chapter. Last but not least, for the consideration of confidentiality, all the finalized answers to the stakeholder questionnaire (see Table A-4-2 in the Appendix) have been removed.

4.3.3 Step Three: Searching

With the quantitative SVN Model obtained above, the objective of the third step in the SVN analysis is to search for all the possible value paths between any two stakeholders within such a multi-relational network. Specifically, all the value cycles for the focal organization can be taken as the sample space to construct network statistics in order to measure the exchange and structural properties of the SVN: On one hand, value cycles and their utility scores provide a feasible way for the focal organization to compare the relative importance of all the exchange relations, including both direct and indirect ones, with other stakeholders; On the other hand, value cycles also simultaneously capture the information about each stakeholder's structural position in the network—for example, the occurrence of a specific stakeholder in all the value cycles for the focal organization, will obviously vary with its network position.

As introduced in Chapter 3, the Object-Process Network (OPN) [Koo, 2005] developed by the MIT System Architecture Group provides a graphical modeling platform to perform the above searching task. Similar to Figures 3-12 and 3-13, Figures 4-13 and 4-14 show a snapshot for the OPN model and a zoom-in view of this model, respectively.

However, compared to the RuSakOil case (see Figure 3-3), we observe that the SVN of the Project Phoenix case (see Figure 4-3) takes much longer time (from seconds up to hours) to be solved on the OPN platform, with the number of stakeholders increasing from 9 to 14 and the number of value flows increasing from 27 to 74. Although the running time of the OPN model is still manageable for the Project Phoenix case, similar or even worse results have been observed in other applications of the SVN analysis, which raise the concern for the OPN platform to solve those medium and large stakeholder networks and also bring up the opportunity to develop a more effective as well as more efficient software tool for the SVN analysis. This mission is finally accomplished in Chapter 5, starting with an analysis for the shortcomings of the OPN platform and then followed by the development of a new modeling platform using more powerful algorithm and better software design.

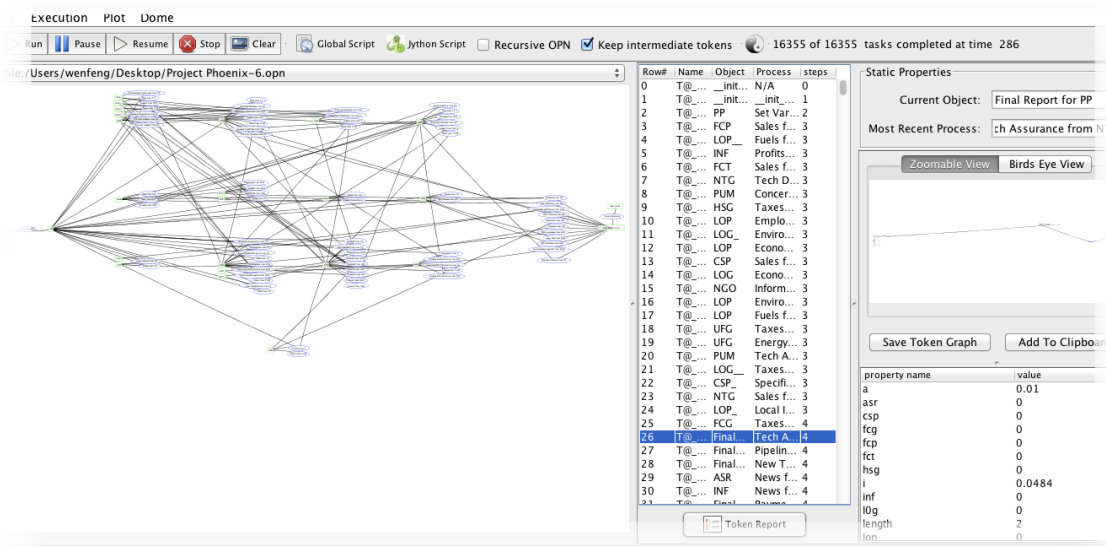


Figure 4-13: OPN Model for the SVN of the Project Phoenix

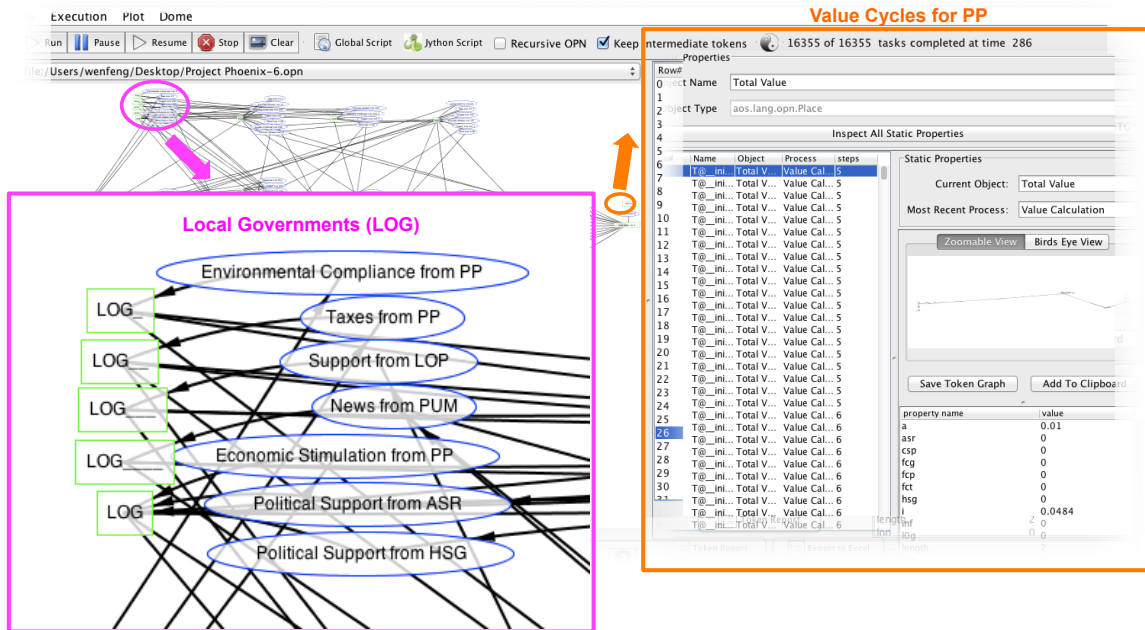


Figure 4-14: Zoom-In View of the OPN Model

Facing the limited computational power of the OPN platform, one simple and feasible solution is to add constraints into the quantitative SVN Model, as discussed in Chapter 3 (see Section 3.2.3). Specifically, this chapter chooses the “Internal Assets” as a constraint for the SVN Model of the Project Phoenix case, for both mathematical and strategic considerations.

The constraint of “Internal Assets” defines the mechanism for stakeholders to convert their inputs to outputs, which can be either monetary or nonmonetary, in the form of categorized resource pools to connect each stakeholder’s inputs with the same category of outputs. Figure 4-15 takes the Local Governments (LOG) in the Project Phoenix case as an example to illustrate how this constraint works. For instance, the “Economic Stimulation” from PP, “Political Support” from the Host State Government (HSG), “Political Support” from the Adjacent State Representatives (ASR), and “Support” from the Local Public (LOP) are four inputs that can add the “Domestic Political Capital” for the Local Governments (LOG), and once these inputs are converted into the political capital, they can be applied by the Local Governments (LOG) as the same type of resources without any difference to exert the “Political Influence” on the Host State

Government (HSG) and the Adjacent State Representatives (ASR) as well as to provide the “Local Government Service” to the Local Public (LOP).

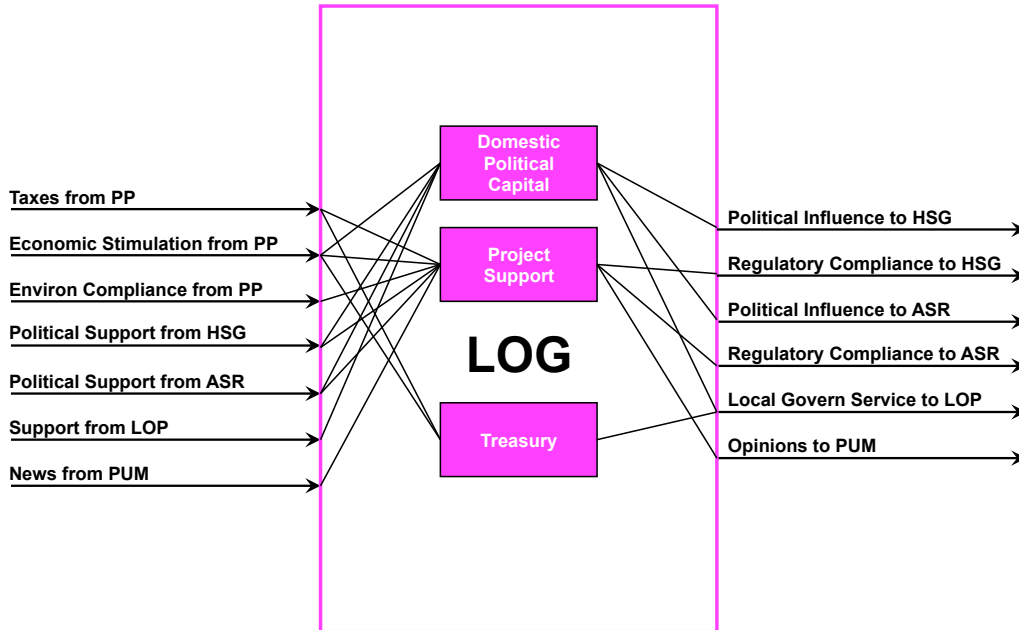


Figure 4-15: Internal Assets within the Local Governments (LOG)

From the mathematical perspective, it is straightforward to understand that the “Internal Assets” within each stakeholder narrow the solution space of the quantitative SVN Model by eliminating those value cycles with unreasonable matches between value flows, and therefore speed the computation on the OPN platform. From the strategic perspective, the constraint of “Internal Assets” adds more rigor to the SVN Model by factoring in the causal relationships between value flows before linking them into a value path or cycle. As such, a lucid logic is presented for the existence of each value cycle and the reason why stakeholders are engaged in a generalized exchange is also partially explained.

In the Appendix, similar to the accompanying documents for value flows shown in Table A-4-1, Table A-4-3 lists the specific “Internal Assets” for each stakeholder in Project Phoenix as well as their formal definitions in order to converge the interpretation from different stakeholder representatives and ensure the credibility of the results from the SVN analysis. In addition, similar to Figure 4-15, Figures A-4-1 ~ A-4-13 visualize the “Internal Assets” constraints for other 13 stakeholders in the Project Phoenix case. Note

that even with the constraint of “Internal Assets”, the inputs of a few stakeholders can still be freely matched to their outputs, and those stakeholders are colored in red purposefully.

4.3.4 Step Four: Analyzing

After adding the above constraint of “Internal Assets”, the quantitative SVN Model for the Project Phoenix case can be solved on the OPN platform much faster (from hours down to minutes). Specifically, when taking Project Phoenix as the focal organization, Figure 4-16 shows the distribution of the utility scores of all the 5039 value cycles for Project Phoenix found in the SVN. From this figure, we observe that only 222 value cycles have a utility score between 0.1 and 0.5, and the utility scores of the remaining 4817 value cycles are lower than 0.1.

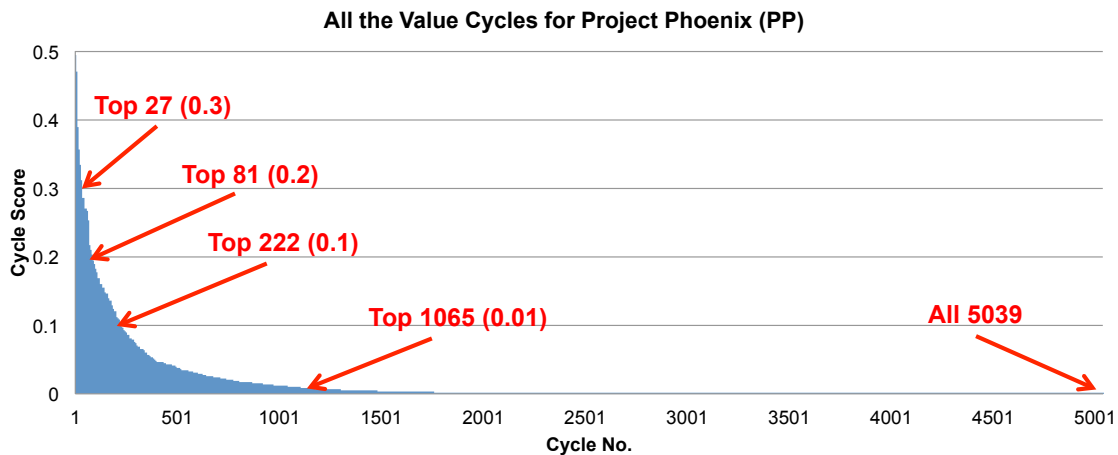


Figure 4-16: Utility Score Distribution of All the Value Cycles for Project Phoenix in the SVN Model

Further, after running the SVN Model on the OPN platform multiple times ($14^2 = 196$), Table 4-2 summarizes the number of possible value paths or cycles between any two stakeholders, and these results can be used to analyze the relationship balance between stakeholders, which are discussed together with the integration of stakeholders and issues in the next Section. In Chapter 5, once the new software tool for the SVN analysis is developed, such a table can be fully obtained at once and much more efficiently.

Table 4-2: Summary for All-Pair-Stakeholder-Relationships in the Project Phoenix Case

	PP	FCG	FCP	FCT	CSP	INF	HSG	ASR	LOG	LOP	NGO	NTG	PUM	UFG
PP	5039	468	468	1402	2	534	770	833	714	392	1000	2	534	468
FCG	167	440	1	195	130	846	985	1389	1100	634	1223	296	758	406
FCP	167	160	161	513	130	846	985	1389	1100	634	1223	296	758	406
FCT	166	124	124	565	130	685	781	1188	938	534	931	295	597	283
CSP	384	474	474	1328	221	667	799	844	762	178	1030	569	545	444
INF	182	534	534	1600	79	466	933	953	847	535	1059	239	409	534
HSG	255	401	401	1165	134	238	1804	344	335	365	327	349	170	392
ASR	296	262	262	732	176	356	505	1603	616	563	590	447	245	244
LOG	466	444	444	1260	254	419	498	254	2364	639	693	670	268	420
LOP	384	353	353	967	221	445	528	492	461	2385	688	569	323	323
NGO	258	372	372	1054	99	279	731	549	517	142	1629	323	247	353
NTG	2	684	684	2050	3	722	1156	1133	993	503	1432	4	722	684
PUM	182	206	206	616	79	57	427	416	396	248	418	239	2156	206
UFG	167	34	34	36	130	465	467	933	671	394	480	296	377	1847

Similar to the RuSakOil case in Chapter 3, in this chapter we also compute network statistics based on all the 5039 value cycles (under the constraint of “Internal Assets” for each stakeholder) for Project Phoenix. With these statistics, the following strategic implications are discussed in order: Important Value Cycles, Important Stakeholders, Important Outputs and Inputs, Important Value Flows, and more importantly, the Comparison of Important Stakeholders between Project Phoenix Managers’ Mental Model, the “Hub-and-Spoke” Model, and the “Network” Model, in order to validate the strength of the SVN analysis for understanding the impacts of indirect stakeholder relationships on the long-term success of large engineering projects.

4.3.4.1 Important Value Cycles

First of all, Figures 4-17 and 4-18 visualize the top 11 value cycles for Project Phoenix in terms of the utility scores of those cycles. For better visibility, the value flows in the same color and line type in Figure 4-18 constitute one value cycle.

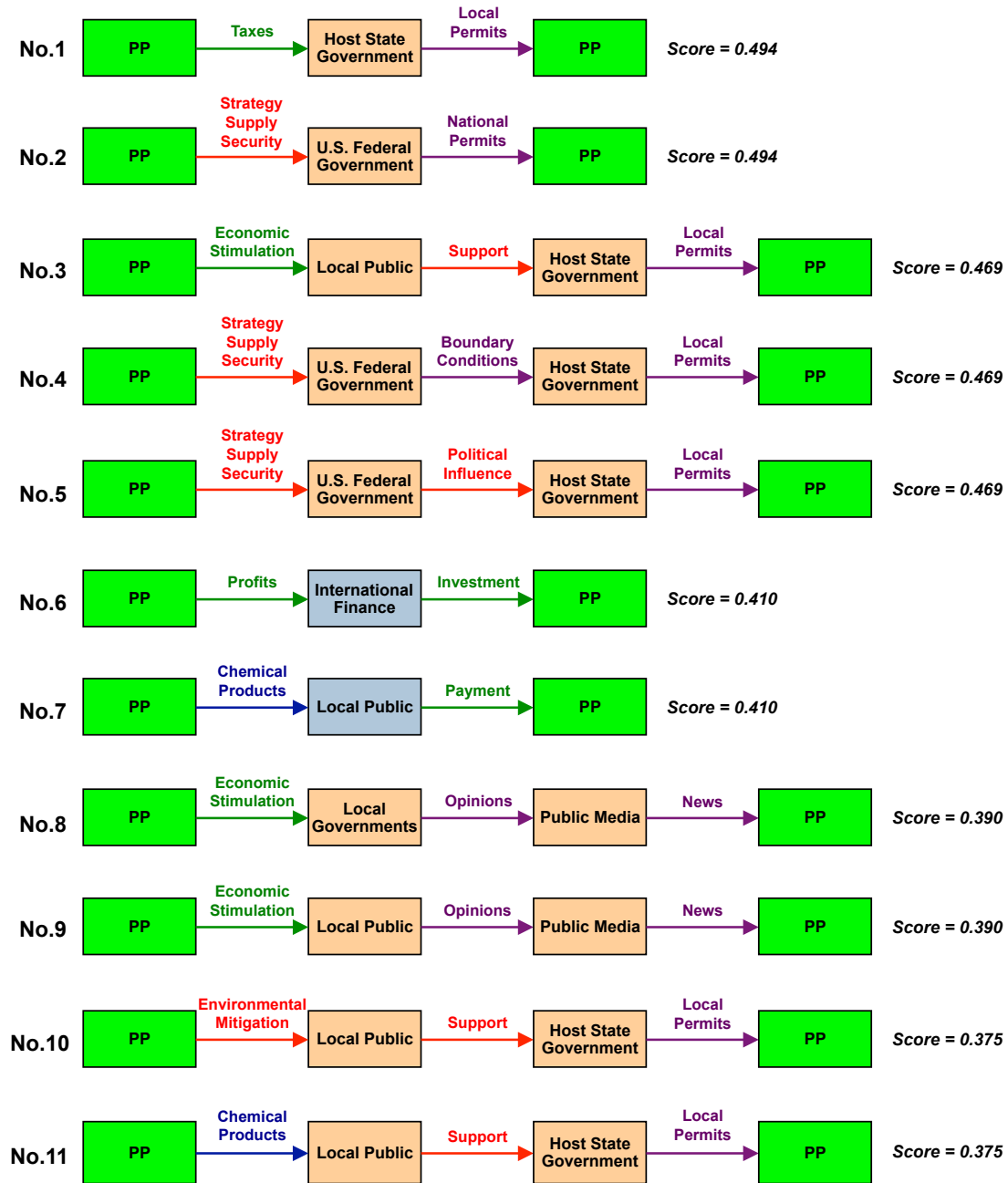


Figure 4-17: Top 11 Value Cycles for Project Phoenix in the SVN Model

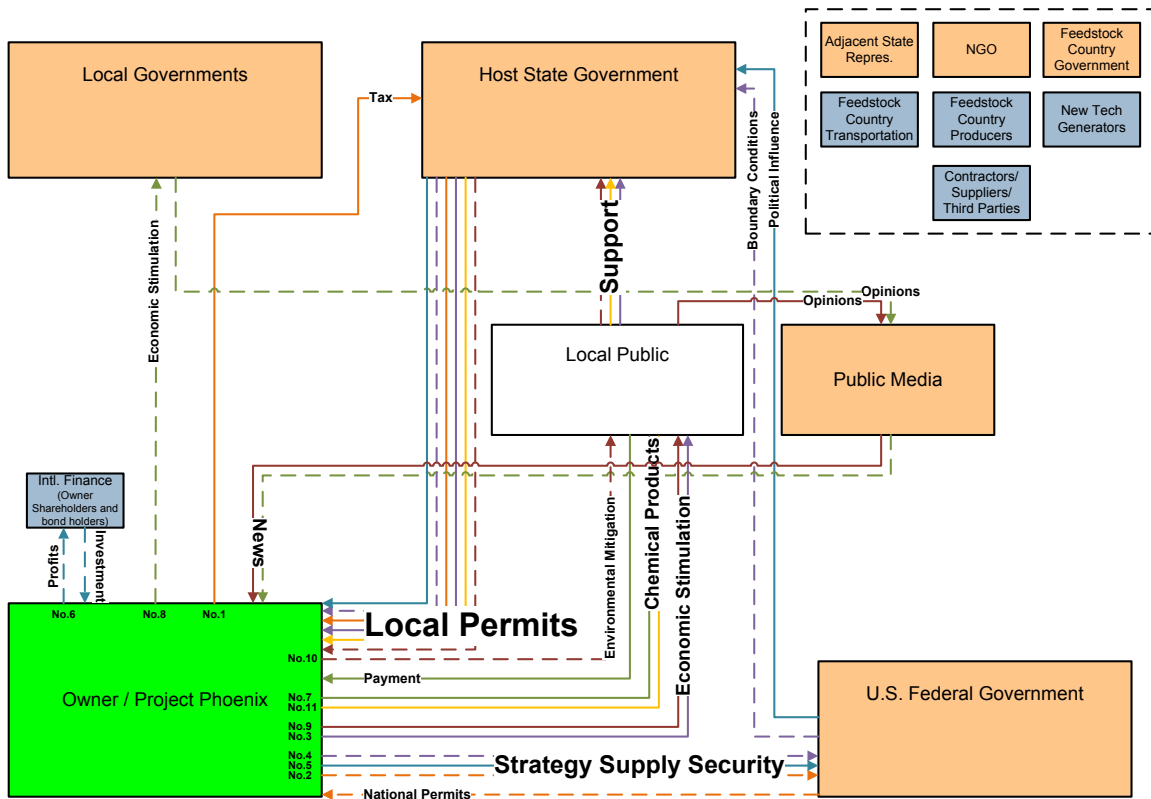


Figure 4-18: Visualization of Top 13 Value Cycles for Project Phoenix in the SVN Model

From the above two figures, three key observations are made as below:

- The top value cycles provide guidance for Project Phoenix to formulate indirect strategies to engage other stakeholders, especially when it is difficult to engage them directly.
- The occurring frequency of each value flow in these top value cycles roughly indicates its relative importance from the perspective of the focal organization. For example, within the top 11 value cycles, on one hand, the most important outputs from Project Phoenix are “Strategic Supply Security” to the U.S. Federal Government (UFG), as well as “Economic Stimulation” and “Chemical Products” to the Local Public (LOP); and on the other hand, the most important inputs for Project Phoenix are “Local Permits” from the Host State Government (HSG) and “News” from the Public Media (PUM). This observation intuitively supports the network statistics constructed in Chapter 3—once expanding the

sample space from the top 11 value cycles to all the 5039 value cycles, these occurring frequencies will become the Weighted Output Occurrence (WOO), Weighted Input Occurrence (WIO), and Weighted Value Flow Occurrence (WVFO), which are formally defined in Equations 3-4 ~ 3-6.

- There are seven stakeholders that do not show up in the top 11 value cycles for PP. This can be taken as the theoretical basis to collapse out less important stakeholders in order to better manage both the computational and analytical complexities in the SVN Model.

4.3.4.2 Important Stakeholders

Defined in Equation 3-3, the Weighted Stakeholder Occurrence (WSO, a.k.a. Exchange Centrality I or Crawley Centrality I) quantifies the relative importance of each stakeholder for the focal organization from both the exchange and structural perspectives. Specifically, Figure 4-19 shows the calculated WSO for Project Phoenix in the SVN Model (see Figure 4-3). We observe that the most important stakeholders for Project Phoenix are the Public Media (PUM), Local Public (LOP), Host State Government (HSG), and so on. Note that as a reference, the numerical value of the first blue bar in this figure always equals 1.0, because the focal organization appears in all its value cycles by definition.

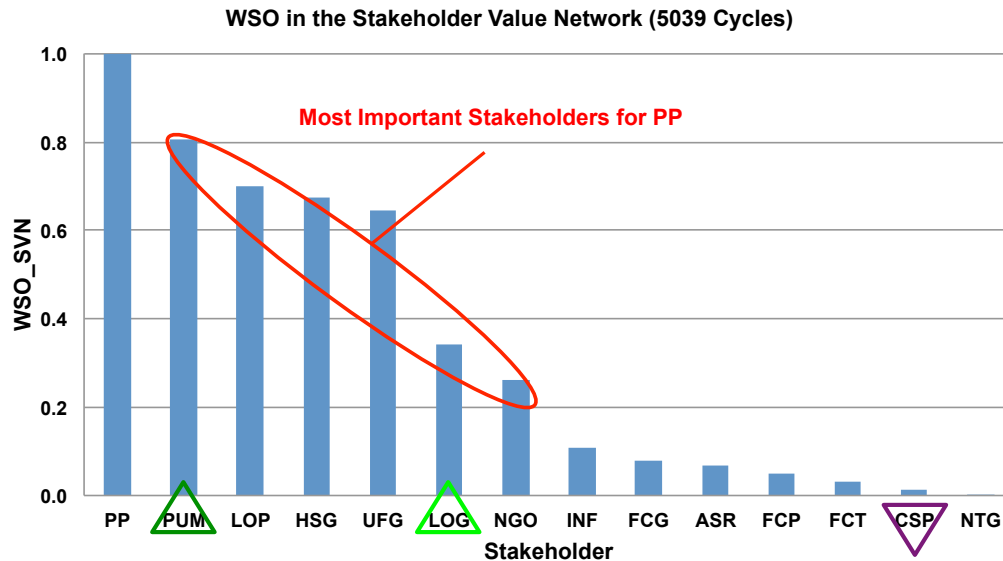


Figure 4-19: Weighted Stakeholder Occurrence (WSO) for Project Phoenix in the SVN Model

4.3.4.3 Important Outputs and Inputs

Using Equations 3-4 and 3-5, Figures 4-20 and 4-21 calculate the Weighted Output Occurrence (WOO) and the Weighted Input Occurrence (WIO) for Project Phoenix in the SVN Model (see Figure 4-3), respectively. By definition, the sum of WOO and the sum of WIO should always equal 1.0.

From these two figures, the following observations are made:

- WOO helps identify that the top six high-leverage outputs from Project Phoenix are “Economic Stimulation”, “Chemical Products”, “Environmental Mitigation”, and “Employment” to the Local Public (LOP), “Economic Stimulation” to the Local Governments (LOG), as well as “Strategic Supply Security” to the U.S. Federal Government (UFG). An output with a higher WOO, will have a greater effect on improving the inputs to Project Phoenix at the end of value cycles—if Project Phoenix has additional resources to increase the levels of its outputs, WOO suggests a reasonable order for those resources to be allocated.

- WIO helps identify that the top three affectable inputs for Project Phoenix are “Local Permits” from the Host State Government (HSG), “News” from the Public Media (PUM), and “National Permits” from the U.S. Federal Government (UFG), because if Project Phoenix increases all its outputs by one unit, WIO indicates how much each input for Project Phoenix would increase accordingly.

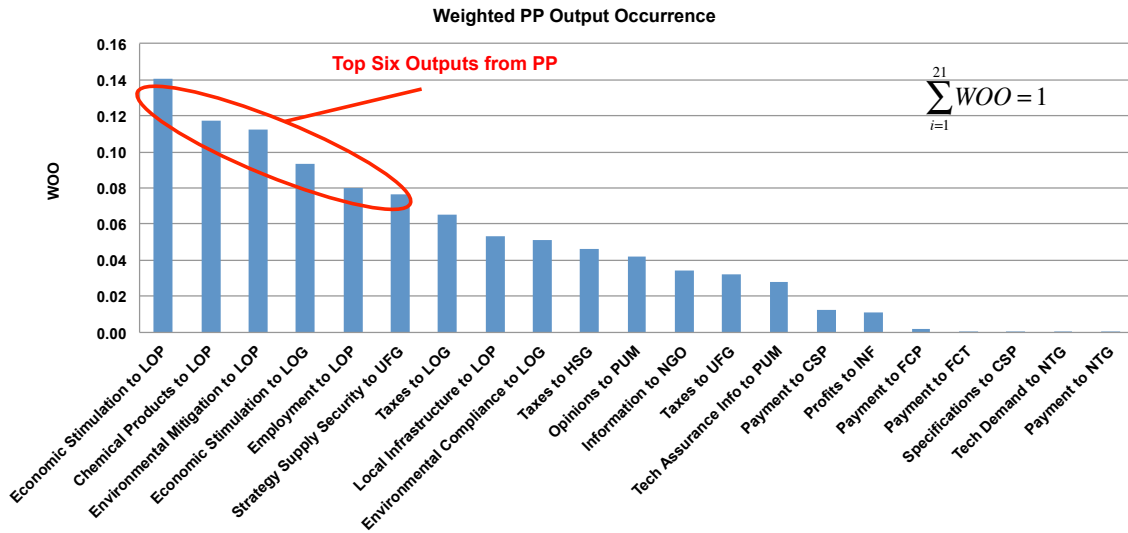


Figure 4-20: Weighted Output Occurrence (WOO) for Project Phoenix in the SVN Model

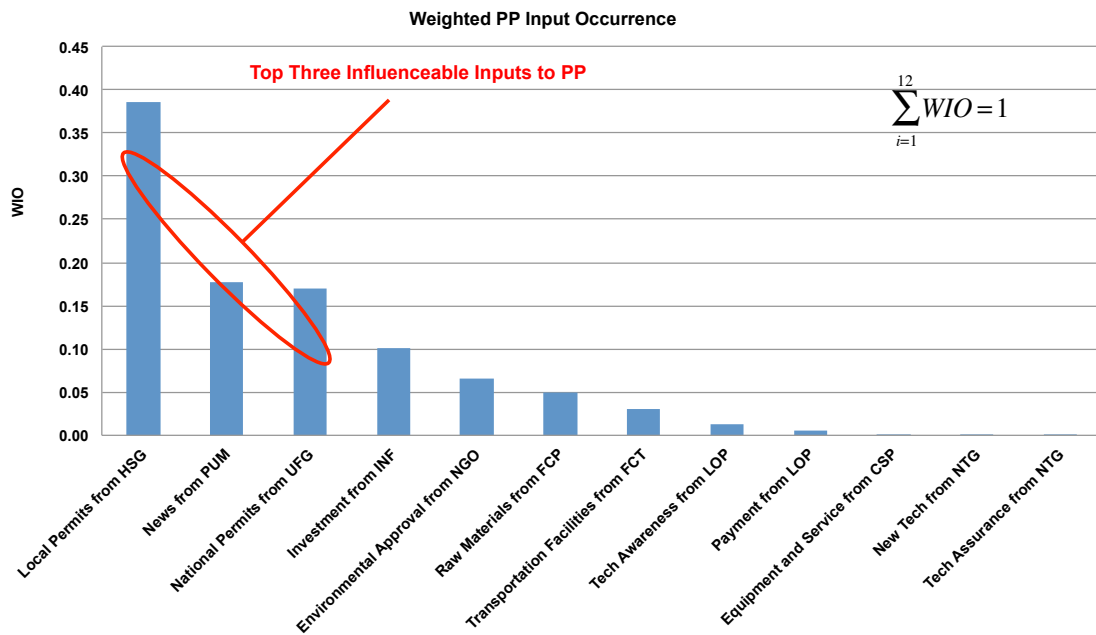


Figure 4-21: Weighted Input Occurrence (WIO) for Project Phoenix in the SVN Model

4.3.4.4 Reduced Complexity for Stakeholder Networks

Using Equation 3-6, the Weighted Value Flow Occurrence (WVFO) can also be calculated. Based on the WVFO, Figures 4-22 and 4-23 identify the top 13 and top 30 value flows for Project Phoenix in the SVN Model (see Figure 4-3), respectively. By definition, the sum of WVFO should always equal 1.0, like the WOO and WIO (see Figures 4-20 and 4-21).

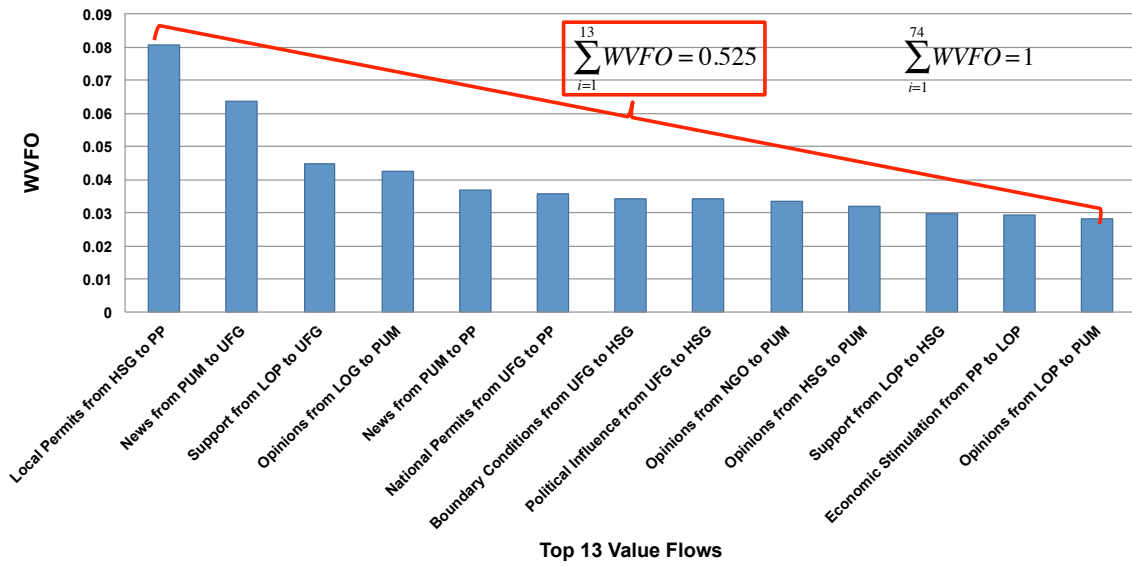


Figure 4-22: Top 13 Value Flows for Project Phoenix in the SVN Model

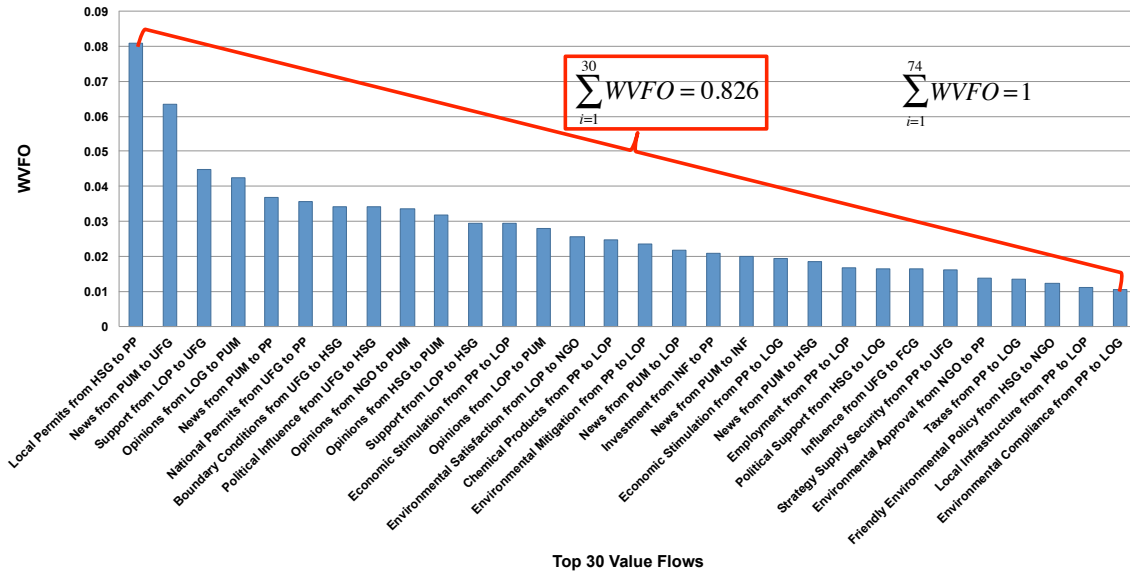


Figure 4-23: Top 30 Value Flows for Project Phoenix in the SVN Model

Similar to the RuSakOil case in Chapter 3, we observe that a few value flows in the Project Phoenix case are significantly more important than the remaining flows in terms of the WVFO—for example, Figure 4-22 shows that less than one fifth of the value flows (13 out of 74) accounts for more than half of the total value weight, and Figure 4-23 further shows the combined weight of less than half value flows (30 out of 74) already exceeds 80% of the total weight. Those top value flows, together with the list of important stakeholders identified by the high WSO, can be used to construct a smaller stakeholder network. With such a smaller SVN Model, which only focuses on the most important stakeholders and value flows, it is possible include more details regarding the internal structure of stakeholders as well as the value exchanges between them within the existing computational and/or analytical limitations.

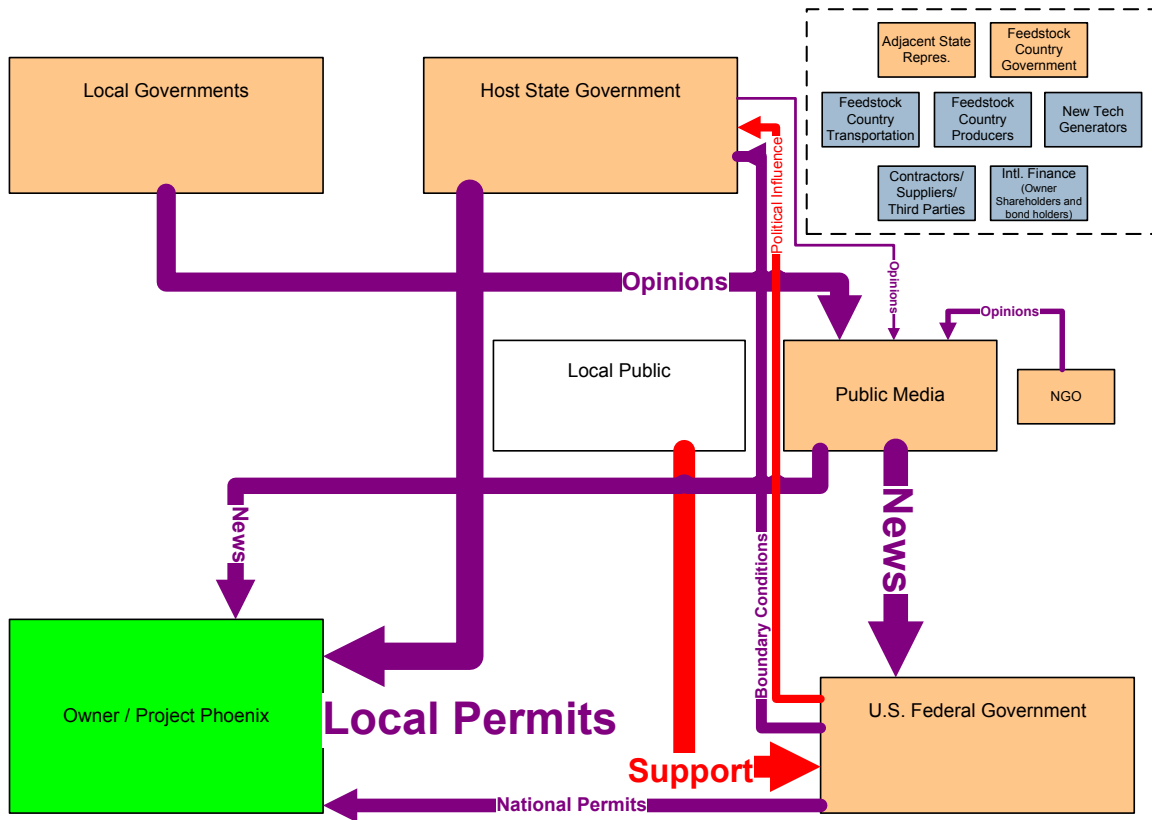


Figure 4-24: Visualization of Top 13 Value Flows for Project Phoenix in the SVN Model

In addition, Figure 4-24 visualizes the top 13 value flows for Project Phoenix in the SVN Model through adjusting the thickness of each flow proportionally to its ranking (see Figure 4-22). From this figure, a few more observations are made as below:

- The types of all the top 13 value flows are either political or information, which are mediated only by the nonmarket environment, and none of the goods/service and financial flows makes the list. This observation confirms the previous findings on the density of different types of value flows (see Figures 4-4 ~ 4-7 and Section 4.3.1.3)—as argued by McAdam, Boudet, Davis, et al. [2010], today the nonmonetary and intangible social relationships are gradually replacing the monetary and tangible economic relationships to become the main challenges for large engineering projects, especially when these projects cross the borders of different countries [Miller and Lessard, 2001]—this phenomenon has far-reaching significance, which is discussed in the next Section based on the

comparisons between Project Phoenix Managers' Mental Model, the "Hub-and-Spoke" Model, and the "Network" Model.

- There are seven stakeholders not involved with the top 13 value flows in the network. This can be taken as the theoretical basis to collapse out less important stakeholders in order to better manage both the computational and analytical complexities in the SVN Model.
- While Figure 4-24 looks similar to Figure 4-18, which visualizes only the top 11 value cycles for Project Phoenix, one basic difference between these two figures is their sample space. Figure 4-18 only takes 11 value cycles while Figure 4-24 takes all the 5039 value cycles—therefore when constructing a smaller SVN Model for more fine-grained analysis, Figure 4-24 or WVFO provides a more solid basis than Figure 4-18 or Important Value Cycles.

4.3.5 Impacts of Indirect Stakeholder Relationships

As the climax of the SVN analysis for the Project Phoenix case, this section compares a short list of important stakeholders obtained from Project Phoenix Managers' Mental Model, the "Hub-and-Spoke" Model, and the "Network" Model, in order to validate the strength of the SVN analysis for understanding the impacts of indirect stakeholder relationships for the long-term success of large engineering projects.

4.3.5.1 Comparison between the Mental Model and the "Network" Model

As noted in Section 4.2, the Host State Government (HSG) and the U.S. Federal Government (UFG) were the most important stakeholders in Project Phoenix Managers' Mental Model, mainly because from the standpoint of the project managers, the new wastewater discharge permits were among the most direct and important requirements for Project Phoenix to be conducted successfully, while the HSG and UFG were exactly the stakeholders in charge of issuing these permits on the local and national levels respectively. Meanwhile, we also conclude that PP's project managers had not paid

enough attention to the Public Media (PUM) and the Local Public (LOP) before seeing the unanticipated protest from them.

Now recall the most important stakeholders ranked by the WSO in the “Network” (SVN) Model: From Figure 4-19, it is clear that the PUM and LOP are the most important stakeholders for Project Phoenix, which means the results from the SVN analysis match the later facts better than Project Phoenix Mangers’ Mental Model in this retrospective case study, through including both direct and indirect relationships in the stakeholder network.

4.3.5.2 Comparison between the “Hub-and-Spoke” and “Network” Models

The “Hub-and-Spoke” Model (see Figure 4-8) is derived from the “Network” (SVN) Model for Project Phoenix (see Figure 4-3), by including only the direct relationships between the focal organization (PP) and its stakeholders. Following the same steps in the SVN analysis as the “Network” (SVN) Model, Figure 4-25 shows the rank of stakeholder importance in terms of their WSO for the “Hub-and-Spoke” Model. Comparing Figure 4-25 with Figure 4-19, three major differences are apparent: First, the Public Media (PUM) jumps from the fourth important stakeholder to the first important one; Second, the Local Governments (LOG) jump from the least important one to one of the most important stakeholders; Third, on the contrary, the Contractors/Suppliers/Third Parties (CSP) become less important in the SVN Model. Recalling the later facts about important stakeholders introduced at the beginning of this case study, it is not difficult to conclude that the SVN Model better reflects the reality, thanks to the consideration of the indirect relationships between stakeholders.

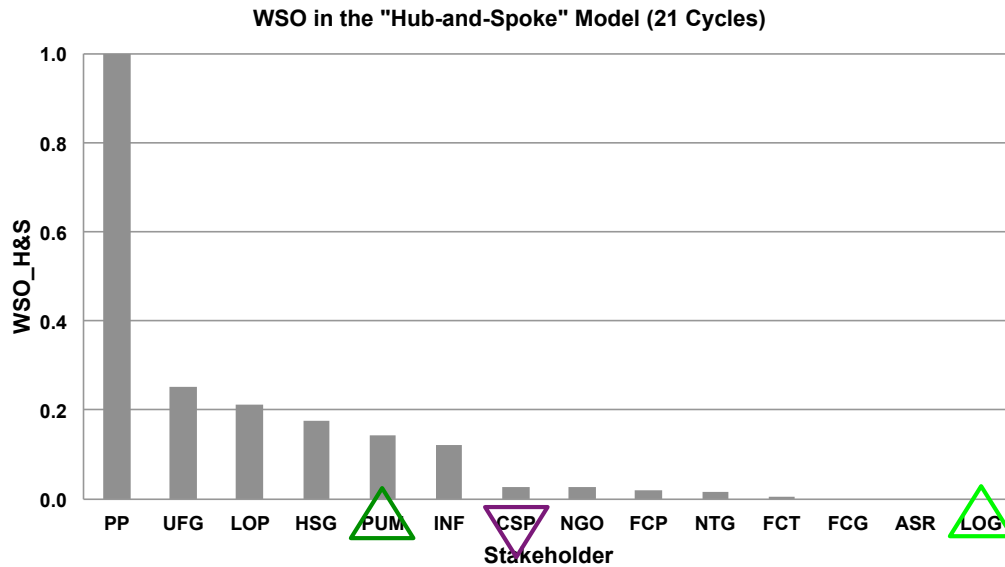


Figure 4-25: WSO for Project Phoenix in the “Hub-and-Spoke” Model

4.3.5.3 Why the Indirect Stakeholder Relationships Matter

The above comparisons between three models have convincingly demonstrated the strength of the SVN analysis for understanding the impacts of indirect stakeholder relationships on the long-term success of large engineering projects. However, a more fundamental question can be raised from these comparisons: “Why do the indirect stakeholder relationships matter so much for today’s large engineering projects such as Project Phoenix?”

Equipped with the relevant theories in social sciences, we argue that the key to answer this important question is the missing link between the types of stakeholder relationships and the patterns for stakeholders to exchange values. As discussed in Chapter 2, economic relationships mainly exist in the form of Restricted Exchange, while social relationships mainly exist in the form of Generalized Exchange.

Based on the bridge between relationship types and exchange patterns, as well as the normative and instrumental origins for Generalized Exchange, the answer to the fundamental question asked at beginning, “Why do the indirect stakeholder relationships

matter so much for today's large engineering projects such as Project Phoenix", comes into place by itself: As observed earlier in this chapter, for today's large engineering projects, the social relationships between stakeholders (including the political and information value flows as defined in this dissertation) prevail over their economic relationships (including the goods/service and financial value flows as defined in this dissertation), in terms of both density (see the decomposition views of stakeholder map in Figures 4-4 ~ 4-7) and importance (see the visualization for top value flows in Figure 4-24). This phenomenon decides the significance of the Generalized Exchange, which consists of indirect stakeholder relationships, as a pattern for stakeholders to exchange values. Therefore, compared to the traditional managerial model and "Hub-and-Spoke" stakeholder model, the strength of the SVN analysis comes exactly from its inclusion of indirect stakeholder relationships or Generalized Exchange as the basic units to measure the exchange and structural properties of the networks, which then determine the distribution of stakeholder power as a consequence [Blau, 1964; Emerson, 1972; Molm, 1990].

In addition, the importance of generalized exchanges for today's large engineering projects can also be understood from the following aspects:

- **Psychological Perspective:** Generalized exchanges can emerge with a variety of reasons and motivations—"from pure altruistic (Sahlins, 1972) to norm-based behavior (Ekeh, 1974) to behavior that is based on rational choice and instrumental incentives (Olson, 1965)" [Levine and Shah, 2003, pp. 3-4].
- **Sociological Perspective:** Generalized exchanges heavily rely on the social relationships mediated by the nonmarket environment and are mainly bounded by the mutual trust among all the participants. Therefore, when social relationships prevail with the waves of education, globalization, and information technology, the significance of generalized exchanges cannot be simply ignored.
- **Economic Perspective:** From Marx to Keynes, to Friedman, and to von Mises and Hayek, different schools of economists have different belief in free market. However, the most recent financial crisis and global economic recession bring

back the heated debate on how free an efficient market should be (see the latest work of Joseph E. Stiglitz, Paul R. Krugman, James K. Galbraith, and J. Bradford DeLong among others). In the foreseeable future, no one can deny the increasing visibility of nonmarket stakeholders, such as governments and NGOs, in the economic activities of modern firms, not mentioning that many of those activities are often across the borders of countries with different political systems, social mechanisms, and culture. Therefore, generalized exchanges potentially provide an effective means for firms to manage these stakeholder relationships mediated by the nonmarket environment without clearly stated economic contracts.

- **Managerial Perspective:** Recently, the importance of generalized exchanges has been recognized by a few leading scholars in the field of stakeholder theory, because generalized exchanges provide “a partial answer to the question of why the whole of stakeholder relationships can be greater than the sum of its parts” [Wicks and Harrison, 2013, pp. 105-106]. Essentially, generalized exchanges are an indirect form of collaboration among a group of stakeholders and can help internalize the previously externalized costs, such as environmental pollutions, so that these stakeholders are able to reach a better agreement on “distributive justice” [Homans, 1961, p. 264], share the benefits and costs, and finally foster the trust between them, which is critical for the long-term success of large engineering projects.

Finally, looking back on the three major assumptions for the SVN discussed in Chapter 2, it is not hard to find that the linkage between the first two assumptions (viz., Relationship Types and Exchange Patterns) is the key to answer the question of “Why the indirect stakeholder relationships matter for today’s large engineering projects”, while the third assumption (viz., Strategic Implications) provides the theoretical foundation to construct network statistics in order to quantitatively measure the impacts of these indirect stakeholder relationships. Moreover, these assumptions have guided three main steps in the framework of the SVN analysis, that is, Quantifying, Searching, and Analyzing, respectively (see Figure 3-1).

4.3.5.4 *Decomposition of the Impacts of Indirect Stakeholder Relationships*

After exploring the reasons behind the significance of indirect stakeholder relationships or Generalized Exchange for today's large engineering projects, the third assumption of the SVN analysis about Strategic Implications provides the theoretical foundation to construct network statistics, which can be used to quantitatively measure the impacts of indirect stakeholder relationships. Specifically, taking the importance of stakeholders as an example, stakeholder power is the outcome of both exchange relations and network positions, based on the Social Exchange Theory (SET) [Blau, 1964; Emerson, 1972; Molm, 1990]. In another word, the impacts of indirect relationships on the ranking of stakeholder importance are exerted through both the exchange and structural properties of the network. However, it remains unclear which properties play a bigger role than the other if not equally, and this information can be very meaningful for the focal organization to formulate effective strategies to manage the relationships (viz., value flows) with its stakeholders, using either the “exchange” approach (increase or decrease the resources allocated to a specific relationship) or the “structural” approach (build a new relationship or destroy an existing one), or even both of them.

In order to obtain such information, we push the frontier of the SVN analysis a bit further, through proposing an innovative way to decompose the impacts of the indirect stakeholder relationships into two parts—one takes into effect through the exchange properties of the stakeholder networks, and the other through the structural properties of the same networks.

As the first step, we define a new network statistics called “Stakeholder Occurrence” or “SO”:

$$\text{Stakeholder Occurrence (SO)} = \frac{\text{Number of the Value Cycles Containing a Specific Stakeholder}}{\text{Number of All the Value Cycles for the Focal Organization}}$$

(Equation 4-1)

Compared to the Weighted Stakeholder Occurrence or WSO (see Equation 3-3), Stakeholder Occurrence or SO does not factor in the utility score of each value cycle, so that the impacts from the exchange properties can be excluded and only the impacts from the structural properties are left in the measurement.

By combining the above two measurements (WSO and SO) with two stakeholder models (“Network” or SVN and “Hub-and-Spoke”) for the Project Phoenix case, four network statistics can be calculated, that is, the WSO calculated from the “Network” Model (WSO_SVN), the SO calculated from the “Network” Model (SO_SVN), the SO calculated from the “Hub-and-Spoke” Model (SO_H&S), and the WSO calculated from the “Hub-and-Spoke” Model (WSO_H&S). Figure 4-26 shows the calculation results.

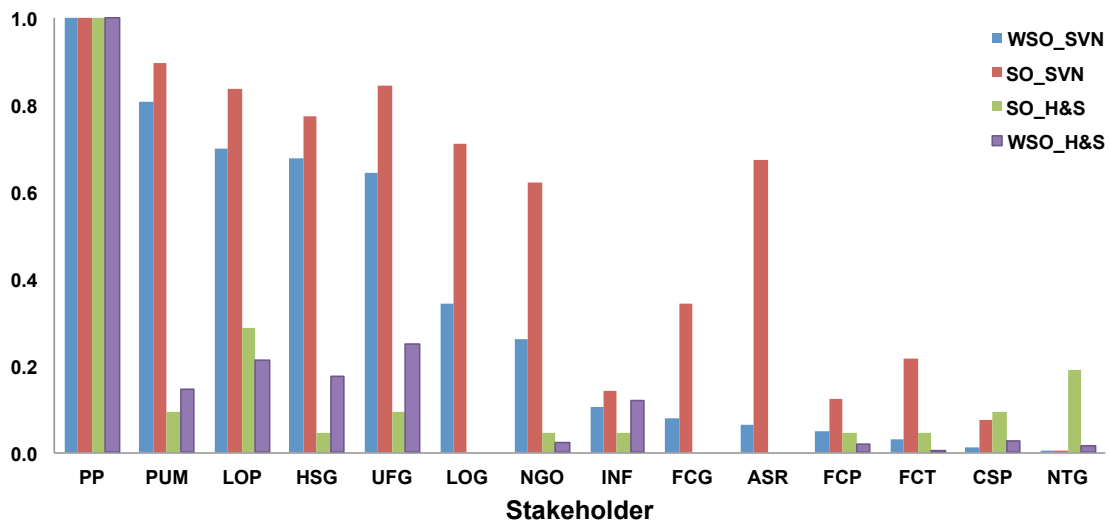


Figure 4-26: Decomposition of the Impacts of Indirect Stakeholder Relationships (Numerical Scale)

Theoretically, based on the definitions for the above four network statistics, the change from “SO_SVN” to “WSO_SVN” only reflects the impacts of the exchange properties in the “Network” Model, and the change from “SO_H&S” to “SO_SVN” only reflects the impacts of the structural properties from the “Hub-and-Spoke” Model to the “Network” Model, while the change from “WSO_H&S” to “WSO_SVN” reflects the integrated impacts of both the exchange and structural properties from the “Hub-and-Spoke” Model

to the “Network” Model. For a better understanding, the differences between these four network measurements are visualized in Figure 4-27.

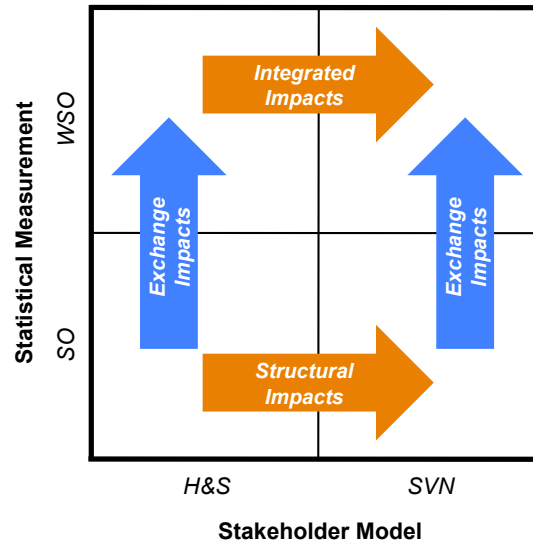


Figure 4-27: Differences between Four Network Measurements

However, astute readers may notice that because of the huge difference of the size of sample space for the “Network” Model (5039 value cycles in total) and the “Hub-and-Spoke” Model (21 value cycles in total), these four network statistics are actually not on the same scale, therefore weakening the explanatory power of the comparisons. In order to overcome this weakness, we define two more statistics to convert the previous numerical scales into a unified percentage scale:

$$\text{Percentage Weighted Stakeholder Occurrence (PWSO)} = \frac{\text{Weighted Stakeholder Occurrence of a Specific Stakeholder}}{\text{Sum (Weighted Stakeholder Occurrence of a Specific Stakeholder)}}$$

(Equation 4-2)

$$\text{Percentage Stakeholder Occurrence (PSO)} = \frac{\text{Stakeholder Occurrence of a Specific Stakeholder}}{\text{Sum (Stakeholder Occurrence of a Specific Stakeholder)}}$$

(Equation 4-3)

Note that the “Specific Stakeholder” in Equations 4-2 and 4-3 does not include the focal organization, which only provides a reference number (always equals to 1.0) for the WSO and SO. The new calculation results are shown in Figure 4-28:

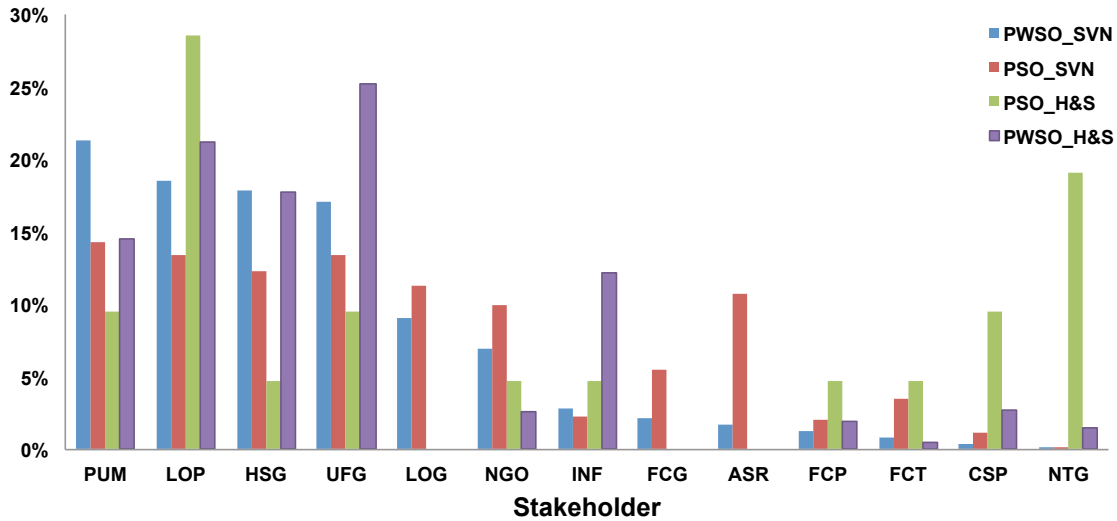


Figure 4-28: Decomposition of the Impacts of Indirect Stakeholder Relationships (Percentage Scale)

For the convenience of comparison, Figure 4-29 visualizes the differences between those percentage network statistics in Figure 4-28:

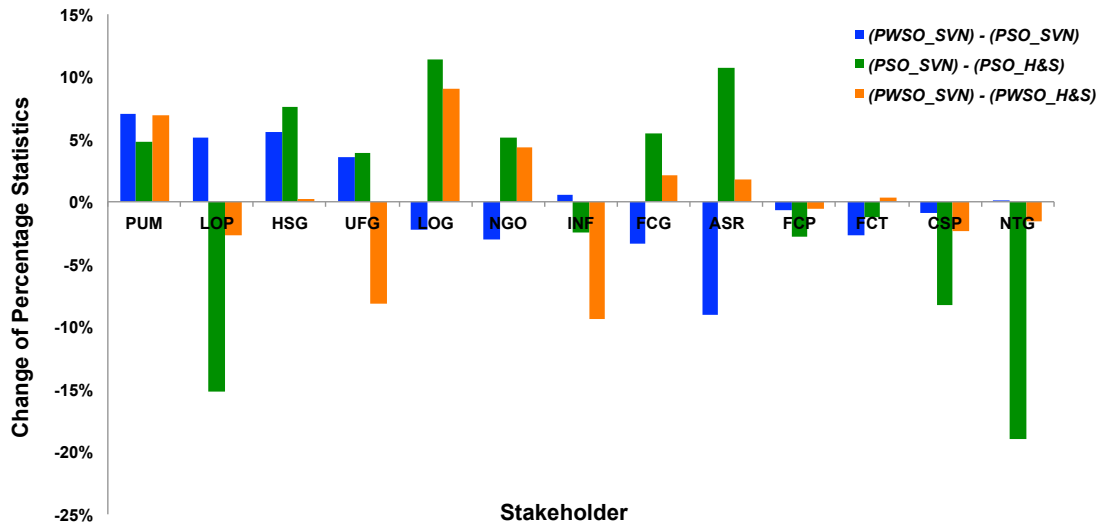


Figure 4-29: Change of Percentage Network Statistics for the Project Phoenix Case

From the above figure, three observations are made as below:

- Observation A: From the “PWSO_H&S” to “PWSO_SVN” (see the orange bars in Figure 4-29), the integrated impacts of both the exchange and structural properties from the “Hub-and-Spoke” Model to the “Network” Model are reflected. We observe that the importance of the Local Governments (LOG) increases most, while the importance of the International Finance (INF) decreases most.
- Observation B: From the “PSO_H&S” to “PSO_SVN” (see the green bars in Figure 4-29), only the impacts of the structural properties from the “Hub-and-Spoke” Model to the “Network” Model are reflected. We observe that the importance of the Local Governments (LOG) increases most, while the importance of the New Technology Generator (NTG) decreases most.
- Observation C: From the “PSO_SVN” to “PWSO_SVN” (see the blue bars in Figure 4-29), only the impacts of the exchange properties in the “Network” Model are reflected. We observe that the importance of the Public Media (PUM) increases most, while the importance of the Adjacent State Representatives (ASR) decreases most.

Based on the above three observations, two strategies for stakeholder management can be further formulated:

- Strategy A: Although the WSO calculated from the “Network” Model shows that the Public Media (PUM) and Local Public (LOP) are the most important stakeholders for Project Phoenix (see Figure 4-19), Observation A counter-intuitively points out neither of them is the stakeholder gaining the most advantage when switched from the traditional “Hub-and-Spoke” Model—surprisingly, that stakeholder is the Local Governments (LOG), who should therefore not be missed in the list of top priorities for PP’s managers. In addition, if Project Phoenix wants to engage the Local Governments (LOG) to change the outcome of the previous SVN, Observation B suggests that the “structural”

approach (for example, building new relationships instead of allocating more resources) should be first considered, because the additional advantage gained by the Local Governments (LOG) mainly comes from its structural position in the “Network” Model.

- Strategy B: According to Observation C, in the “Network” Model, the Public Media (PUM) is the stakeholder gaining the most advantage when adding the utilities of indirect relationships into calculations. Therefore, if Project Phoenix wants to engage the Public Media (PUM) to change the outcome of the previous SVN, the “exchange” approach (for example, allocating more resources instead of building new relationships) should be first considered.

Similarly, more interesting strategies can be systematically formulated with the useful information obtained from the decomposition of the impacts of indirect stakeholder relationships, which instills the SVN analysis with more instrumental power, in addition to its descriptive accuracy demonstrated by the striking comparisons of important stakeholders between three models.

For a more general situation, we can classify the stakeholders for a focal organization into four categories, in terms of the contribution levels of exchange relationships and network structures in the importance or power of stakeholder (see Figure 4-30):

- **Wealthy Stakeholder:** stakeholders only with exchange advantages are “wealthy” but not necessarily powerful;
- **Central Stakeholder:** stakeholders only with structural advantages are “central” but not necessarily powerful;
- **Powerful Stakeholder:** stakeholders with both exchange and structural advantages are powerful;
- **Powerless Stakeholder:** stakeholders with neither exchange nor structural advantages are powerless.

According to the above classification, we further come up with a simple typology of corresponding measurement and management strategy for each category of stakeholders (see Figure 4-30):

- **Structural Strategy:** for wealthy stakeholders (measured by the difference between WSO_SVN and SO_SVN), it would be more effective for firms to take strategies (such as building new relationships or severing current relationships) to gain more structural advantages, in order to balance the exchange advantages of these stakeholders;
- **Exchange Strategy:** for central stakeholders (measured by SO_SVN), it would be more effective for firms to take strategies (such as increasing or decreasing the resources allocated to specific relationships) to gain more exchange advantages, in order to balance the structural advantages of these stakeholders;
- **Integrated Strategy:** for powerful stakeholders (measured by WSO_SVN), firms should take an integrated strategy to simultaneously cope with the exchange and structural advantages of these stakeholders;
- **Null Strategy:** for powerless stakeholders (measured by WSO_SVN), firms should wait until the power status of these stakeholders change (with the passage of time or with the availability of more information).

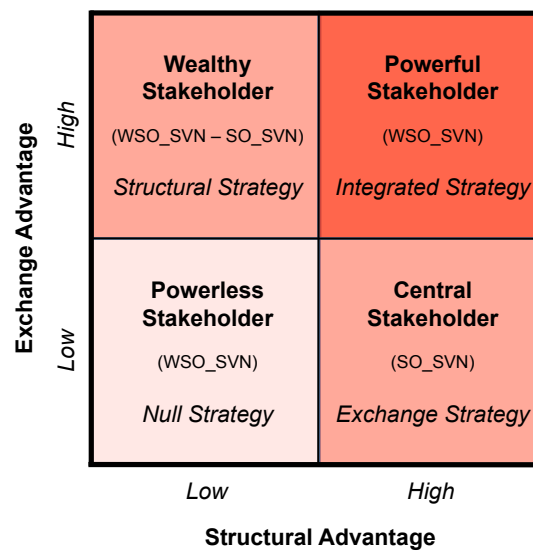


Figure 4-30: Typology for Stakeholder Power and Corresponding Measurement and Strategy

The above in-depth exploration and discussion on the impacts of indirect stakeholder relationships complete the standard SVN analysis for Project Phoenix, using the four-step modeling framework shown in Figure 3-1. Next, as planned at the beginning of this chapter, an extended SVN analysis is conducted for the same Project Phoenix case with the integration of the Strategic Issue Management, an important and alternative way of mapping an organization's "institutional fields" [Dimaggio and Powell, 1983; North, 1990, 1991; Scott, 1987, 2002, 2005].

4.4 Integration between Stakeholders and Issues

In this section we present an alternative perspective on the SVN analyzed above. Rather than focus on all relationships among all stakeholders, we focus on all value flows involving a particular type of issue. We then integrate the stakeholder and issue perspectives in order to strengthen the SVN analysis from the analytical perspective by crystalizing the causal mechanisms behind different stakeholder balance emerging from the network of value exchanges, as well as from the computational perspective by providing a justifiable principle to manage the complexity of large stakeholder networks.

As a starting point, we choose a definition of strategic issues and based on that definition, identify four major issues in the Project Phoenix case, and then develop the corresponding four "Issue Networks" [Frooman, 2010; Lucea, 2007; Lucea and Doh, 2012]. After that, the standard SVN analysis is conducted for these Issue Networks one by one. Finally, the strategic implications of the analysis results are interpreted from two perspectives: (1) the stakeholder balance within a single issue, (2) the stakeholder balance across multiple issues. Note that for the calculations of the utility scores of value cycles, the new "*abc*²" rule is applied throughout all four Issue Networks.

4.4.1 Issue Identification and Issue Networks

First, after comparing several definitions of strategic issues, we choose the most comprehensive one given by Lucea [2007, p. 26]: “Issues are focal and concrete events such as a project, a product, or a firm policy that generate gaps between the expectations of a number of stakeholders and the firm’s behavior. These events and the gaps generated by them can evolve with time and therefore need managerial attention in a timely manner.”

Based on the above definition and recalling the previous introduction to Project Phoenix, it is obvious that the key point of this case is the gap it generated between the expectations from Public Media (PUM) and Local Public (LOP) for clean environment, and Project Phoenix’s potential behavior to emit more pollutants to the local environment. In addition, the project is not an isolated event existing in vacuum but also inseparably connected to other activities/policies of owner of the project at the same location, which can have positive impacts to close the gap generated by the current project, more specifically, the new pollutant discharge permits. Through examining the main activities of Project Phoenix and the general expectations from its stakeholders, it is not difficult to find these relevant activities/policies: Providing products from a domestic source at low cost, Creating more jobs, Building local infrastructures, and Paying taxes.

In summary, there are four major issues in the Project Phoenix case:

- **Issue 1: Local Economic Stimulus** (Infrastructures, Products, and Jobs)
- **Issue 2: General Economic Performance** (Taxes)
- **Issue 3: Local Environmental Protection** (Pollutant Permits)
- **Issue 4: National Security** (Domestic Supply of Products)

Using the above issues as the “focal and concrete events” to identify the primary participation (shown in bold fonts and thick lines) of stakeholders and the relevant relationships (shown in regular fonts and thin lines) between them, the previous stakeholder map for Project Phoenix (see Figure 4-3) can be converted into four smaller

“Issue Networks” (see Figure 4-31 as well as Figures A-4-14, A-4-18, and A-4-22 in the Appendix).

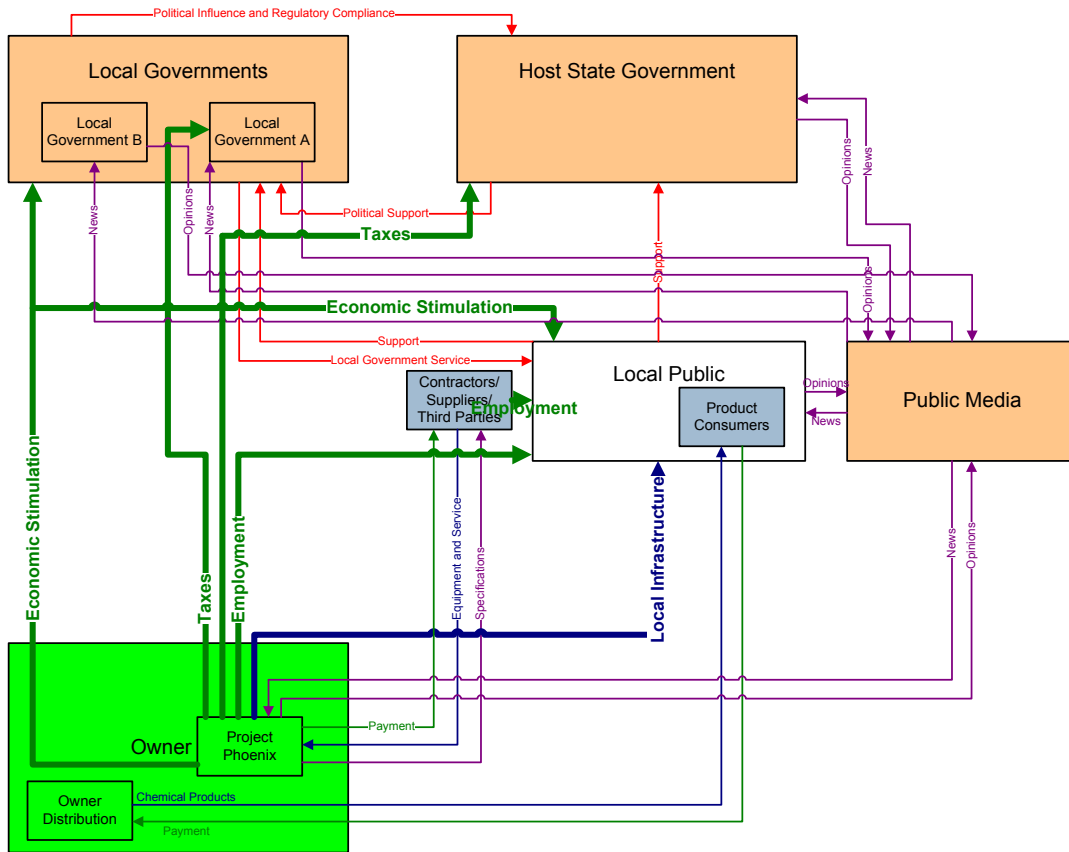


Figure 4-31: Issue Network 1 of “Local Economic Stimulus”

4.4.2 Stakeholder Balance within A Single Issue

Taking the Issue Network 1 of “Local Economic Stimulus” as an example, the implications of stakeholder relationship balance within a single issue can be interpreted in three ways: stakeholder balance (see Figure 4-32), net transaction value (see Figure 4-33), and the impacts of indirect transactions (see Figure 4-34). Similar results for other three Issue Networks are collected in the Appendix (see Figures A-4-14 ~ A-4-25).

4.4.2.1 Stakeholder Balance

- **Definition:**

- In Figure 4-32, blue bars represent the total transaction value from Project Phoenix to its stakeholders, while red bars represent the total transaction value from these stakeholders back to Project Phoenix;
- In Figure 4-32, the right graph shows the value of direct transactions between Project Phoenix and its stakeholders in the “Hub-and-Spoke” Model, while the left graph shows the value of both direct and indirect transactions between Project Phoenix and its stakeholders in the “Network” Model;

- **Implication:**

- For a specific balance where blue bar is longer than red bar, Project Phoenix is more powerful than that stakeholder because Project Phoenix provides more value to the stakeholder than the stakeholder provides to itself, vice versa;
- From the “Hub-and-Spoke” Model to the “Network” Model, the scale of transaction value generally becomes much larger because of the inclusion of indirect transactions;
- All the stakeholder balance comparisons are made under a specific issue (viz., Local Economic Stimulus, General Economic Performance, Local Environmental Protection, or National Security) and based on a specific model (viz., “Hub-and-Spoke” or “Network”).

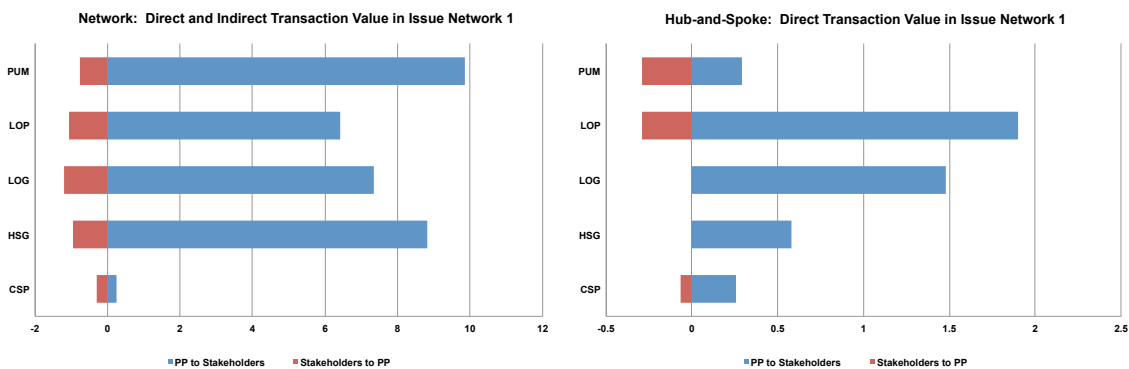


Figure 4-32: Stakeholder Balance in Issue Network 1

4.4.2.2 Net Transaction Value

- **Definition:** In Figure 4-33, “Net Transaction Value = Value from Project Phoenix to Stakeholder – Value from Stakeholder to Project Phoenix”;
- **Implication:**
 - Based on the implication of stakeholder balance, Project Phoenix is more powerful than the stakeholder if the corresponding net transaction value is positive, vice versa;
 - Project Phoenix’s power over the stakeholder will increase with the net transaction value, vice versa;
 - From the “Hub-and-Spoke” Model to the “Network” Model, if the net transaction value between Project Phoenix and a stakeholder increases (especially from negative to positive), it would be beneficial for Project Phoenix to take the indirect strategies to engage that stakeholder, vice versa;
 - All the above implications are made under a specific issue and the cross-issue comparisons should also be taken into consideration (see Section 4.4.3).

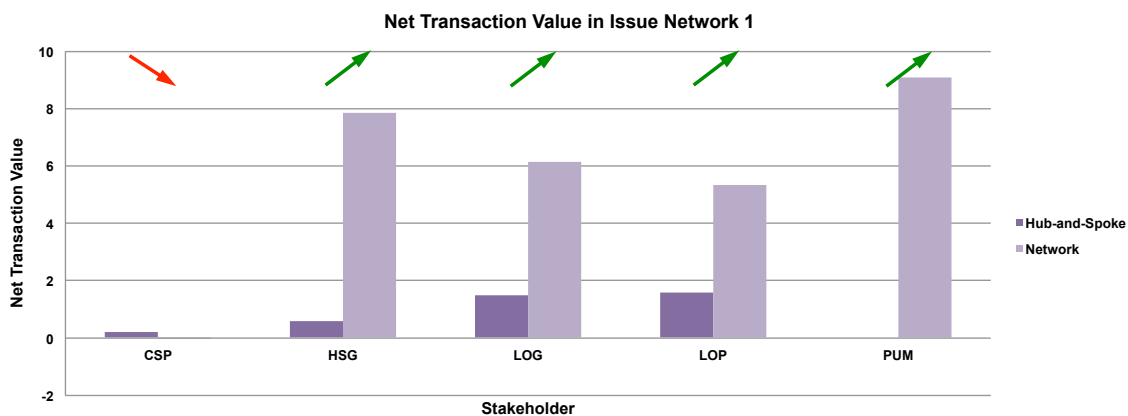


Figure 4-33: Net Transaction Value in Issue Network 1

4.4.2.3 Impact of Indirect Transactions

- Definition:** In Figure 4-34, blue bars represent the inputs for Project Phoenix from a specific stakeholder in the “Network” Model, red bars represent Project Phoenix’s outputs to a specific stakeholder in the “Hub-and-Spoke” Model, and green bars represent Project Phoenix’s outputs to a specific stakeholder in the “Network” Model.
- Implication:** Assuming in the real world stakeholders always know how to apply the indirect transactions to leverage the inputs for Project Phoenix, the increase from red bar to green bar actually reflects the additional strength which Project Phoenix can gain from the indirect transactions from itself to stakeholders. In another word, Figure 4-34 quantifies the benefits of indirect stakeholder influencing strategies taken by Project Phoenix.

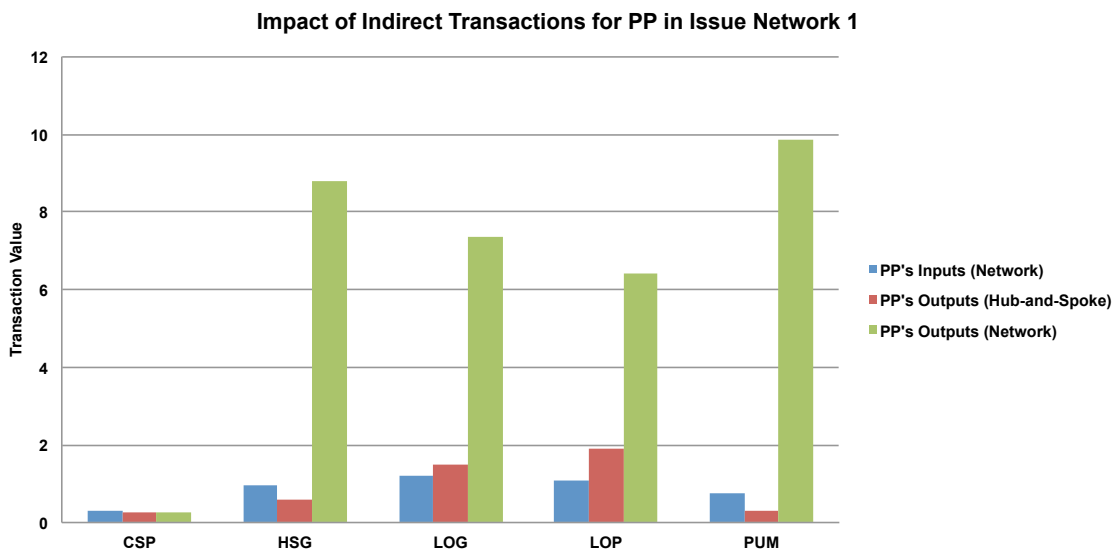


Figure 4-34: Impact of Indirect Transactions for Project Phoenix in Issue Network 1

4.4.3 Stakeholder Balance across Multiple Issues

The same analysis can be conducted for other three Issue Networks (Figures A-4-14 ~ A-4-25 in the Appendix). More importantly, by putting the results from each Issue Network together, an interesting cross-issue comparison of relationship balance between two stakeholders can be obtained.

For example, Figure 4-35 visualizes the relationship balance between Project Phoenix and the Local Public (LOP) across four Issue Networks. From this figure, the following two conclusions are made:

- In the “Hub-and-Spoke” Model, which only includes the direct relationships between Project Phoenix and LOP, Project Phoenix seems to have almost the same power (viz., Net Transaction Value closes to zero) as LOP on different issues. However, this observation neither reflects the later facts in the Project Phoenix case nor provides help to formulate effective stakeholder strategies.
- In the “Network” Model, which includes both direct and indirect relationships between Project Phoenix and LOP, Project Phoenix is much more powerful than LOP on Issue 1 of “Local Economic Stimulus”, but is less powerful than LOP on Issue 3 of “Local Environmental Protection”, measured by the Net Transaction Value. Obviously this observation reflects the later facts well and also provides the direction to formulate stakeholder strategies—for example, Project Phoenix can utilize its strength on Issue 1 to make up for its weakness on Issue 3 to better manage its relationship with LOP.

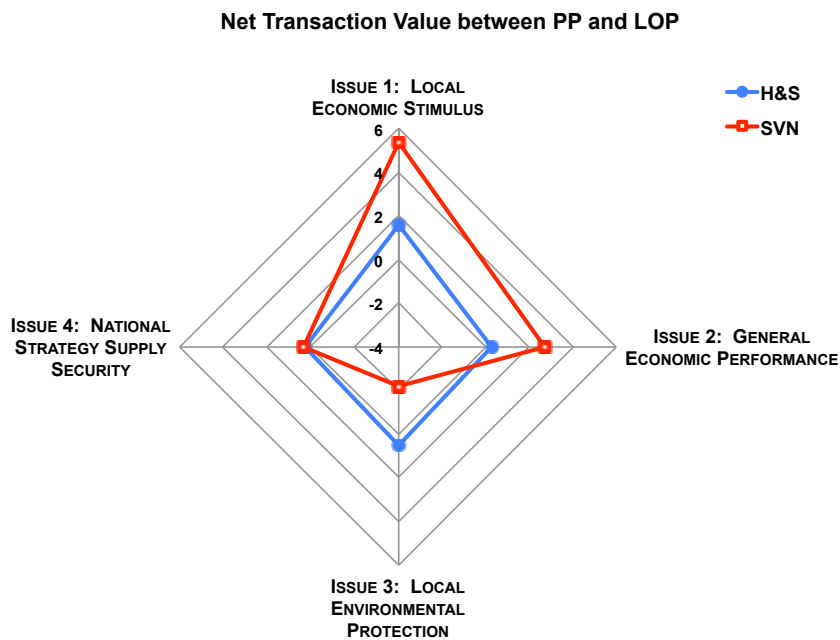


Figure 4-35: Relationship Balance between Project Phoenix and LOP across Four Issues

Similarly, a few more cross-issue comparisons of relationship balance can also be obtained and have been collected in the Appendix (see Figures A-4-26 ~ A-4-28).

4.4.4 More Observations for the SVN Model and the Issue Networks

Reflecting on the previous findings from the SVN Model (see Section 4.3) and the Issue Networks (see Section 4.4), a few more important observations are made as below:

- Managers' Mental Model is very similar to the "Hub-and-Spoke" Model;
- The "Hub-and-Spoke" Model and Managers' Mental Model both miss the Public Media and Local Government as important stakeholders;
- The SVN Model identifies the importance of the Public Media and Local Government, even with only prior information;
- Issue Networks arrive to the same conclusions as the SVN Model, with much simpler analysis;
- Issue Networks provide greatest normative power since they identify those stakeholders that place large values (positive and negative) on the two opposing types of issues (taxes and jobs vs. pollutions) and thus can link them internally, as well as those stakeholders that are "closest" to each other to effect this "issue trade". The central issue for Project Phoenix is that it has negative balance on pollutions and positive balance on taxes as well as jobs, but that in general these apply to different stakeholders;
- Under the above circumstance, generalized exchanges, which include more than two parties in value exchange, can certainly shed light on formulating "indirect" strategies to simultaneously influence the stakeholders with positive balance and those with negative balance.

4.5 Chapter Summary

In this chapter, the four-step modeling framework developed in Chapter 3 is applied to conduct the SVN analysis for Project Phoenix, a large real-world engineering project. Through this retrospective case study, the descriptive accuracy of the SVN analysis for understanding the impacts of the indirect stakeholder relationships is convincingly validated by the comparison of important stakeholders derived from the Managers' Mental Model¹⁸, the "Hub-and-Spoke" Model, and the "Network" (SVN) Model. After the validation, the reasons for the significance of indirect stakeholder relationships for today's large engineering projects are explored in theoretical depth, and meanwhile a few more network statistics are constructed to understand the influence mechanisms for the indirect stakeholder relationships in order to formulate better implementation strategies.

In addition, two major extensions to the SVN framework, the integration of Stakeholders and Issues as well as a new rule for value propagation, are also applied to the Project Phoenix case. Specifically, the integration of Stakeholders and Issues, through the concept of "Issue Networks", provides more insights on the balance of stakeholder relationships and also helps manage the computational complexity of large SVN models.

Putting Chapters 3 and 4 together, the first module of the main body of this dissertation is now completed (see Figure 1-1), and we are ready to conduct the SVN analysis in practice, from the perspective of a focal organization.

However, a few limitations, especially the computational capability of the OPN modeling platform, are also observed in analyzing the case study in this chapter. This provides an impetus to develop a more effective and efficient modeling platform for the SVN analysis, which we do in Chapter 5. With more computational and/or analytical resources brought by such a new modeling platform, it becomes possible for us to study the implications of the SVN from the whole network perspective as well as to model the multiple organizational hierarchies in the stakeholder networks.

¹⁸ Please note that the Managers' Mental Model was first inferred from publically available information, and then confirmed by our interviews with Project Phoenix's managers. More importantly, we found that the "Hub-and-Spoke" Model is actually the underlying assumption used in the Managers' Mental Model.

CHAPTER 5. METHODOLOGY DEVELOPMENT II: SVN FOR THE WHOLE NETWORK

Written on the Wall at West Forest Temple

*“It’s a range viewed in face and peaks from the side,
Assuming different shapes viewed from far and wide.
Of the Mountain Lu we cannot make out the true face,
For we are lost in the heart of the very place.”*

— A Chinese Poem by SU Shi (1037~1101)

Translated by XU Yuanchong

5.1 Chapter Introduction

This chapter further develops the methodological framework of the SVN analysis building upon the four-step SVN modeling framework established in Chapter 3 and then applied to as well as validated by the Project Phoenix case in Chapter 4. We first expand the sample space from only the value cycles for a focal organization to all the non-duplicate value cycles in the network, and we then construct a new family of network statistics based on the expanded space in order to interpret the strategic implications of the SVN from the perspective of the **Whole Network**, instead of from the perspective of a pre-selected **Focal Organization** as we do in Chapters 3 and 4.

Before the further development of the methodological framework, we had to develop a new modeling platform dedicated to SVN analysis, because the OPN (Object-Process Network) platform [Koo, 2005] was not designed purposefully for the stakeholder

networks and its computational capability is also not satisfactory for dealing with larger sample space required to examine the Whole Network.

In this chapter, we first describe this new modeling platform, which is based on the Danielson [1968] algorithm that originated from the circuit theory in electrical engineering and utilizes the multiplication of the Dependency Structure Matrix (DSM, a.k.a. Design Structure Matrix or the Adjacency Matrix) [Browning, 1998; Eppinger et al., 1990, 1994; Steward, 1981a, 1981b] to search for all the simple cycles in a graph. In addition to a better computational performance, this new modeling platform (“the DSM modeling platform” hereafter) provides more convenience and flexibility for the network analysis.

Once the DSM modeling platform is developed and a new family of network statistics is subsequently constructed for the Whole Network, more computational and analytical resources become available for modeling the complicated organizational hierarchies within those large stakeholder organizations, as proposed in Chapter 4. Specifically, at the end of this chapter, five basic principles for hierarchical modeling in the SVN are laid out as an important extension of the Whole Network analysis. These principles are then applied and also tested in Chapter 6, through a prospective case study for China’s Energy Conservation Campaign.

Chapters 5 and 6 advance the analytical perspective of the SVN from a focal organization to the whole network and together constitute the second module of the main body of this dissertation (see Figure 1-1). The second module also presents a method to increase the instrumental power of SVN in terms of generating less biased principles for modeling the organizational hierarchies of large stakeholders.

5.2 Preparation: DSM Modeling Platform

As a necessary preparation for the Whole Network analysis, this section answers two key questions surrounding the new modeling platform dedicated to the stakeholder networks, that is, “Why the Danielson algorithm is chosen” and “How the corresponding DSM platform is constructed”. After that, the RuSakOil case from Chapter 3 is revisited to further explain the benefits of the DSM modeling platform. In addition, for the rare situation when the SVN is too large to be solved even on the DSM modeling platform established in this dissertation, a useful and justifiable technique to find approximate solutions in a timely manner is also introduced, based on the relationships between the modeling results and the length of value cycles in the SVN.

5.2.1 Choice of the Danielson Algorithm

First of all, for the convenience of discussion, the terms and essence of the SVN analysis are reexamined through the lens of the graph theory, followed by a brief complexity analysis for three major algorithms for simple cycle search, which is the central task performed by the third step of “Searching” in the SVN analysis (see Figure 3-1). Based on the results of complexity analysis as well as the convenience for network analysis brought by the unique features associated with the DSM multiplication, the Danielson algorithm is finally chosen as the basis for the new modeling platform.

5.2.1.1 The SVN Analysis through the Lens of Graph Theory

It is important to grasp the following concepts in graph theory [Bollobás, 1998; Diestel, 2005; Gross and Yellen, 2003; Hochbaum, 2008; Weinblatt, 1972] before discussing the choice of appropriate algorithm for the SVN analysis:

- **Vertex:** A node or point in a graph.
- **Degree of Vertex:** The number of edges incident to a vertex in a graph.
- **Edge:** A line with or without the direction in a graph.
- **Multiple Edges:** Edges with the same source and target vertices.
- **Loop:** An edge that connects a vertex to itself.

- **Path:** A sequence of vertices such that from each of its vertices there is an edge to the next vertex in the sequence.
- **Simple Path:** A path with no repeated vertices.
- **Cycle:** A path such that the start vertex and the end vertex are the same.
- **Simple Cycle:** A cycle with no repeated vertices aside from the start/end vertex.
- **Graph:** An ordered pair $G = (V, E)$ comprising a set V of vertices together with a set E of edges, which are 2-element subsets of V .
- **Simple Graph:** A graph that contains no loops or multiple edges. Simple graph is also called strict graph.
- **Multigraph:** A graph that is permitted to have multiple edges. It is noted that loop is often excluded in multigraph.
- **Multidigraph:** A directed graph that is permitted to have multiple directed edges, viz., directed edges with the same source and target vertices.
- **Weighted Graph:** Every edge in the graph is associated with a value.
- **Complete Graph:** A graph in which each pair of vertices is connected by an edge. Complete graph is also called universal graph.

Comparing the above concepts with the terms defined by the SVN analysis in this dissertation, it is not difficult to find that, using the language of graph theory, “stakeholder” is a vertex, “value flow” is an edge, “value path” is a simple path, “value cycle” is a simple cycle, and the “SVN” is a weighted multidigraph. Further, based on the four-step modeling framework (see Figure 3-1), the central task of the SVN analysis is actually to enumerate all the simple cycles in a weighted multidigraph, for a pre-selected focal vertex.

In modern graph theory, the condition of simple graph is usually implied, and multigraph has not been studied as often as simple graph. However, the research of simple cycles can be traced back to almost three hundred years ago—in 1735, Euler solved the classical problem known as the “Seven Bridges of Königsberg” and discovered the Euler’s Theorem [1736], which is often considered as the first theorem of graph theory [Alexanderson, 2006, p. 567]: A finite graph has an Euler tour (viz., a single non-simple

cycle that covers the edges of the graph) if, and only if, it is connected and every vertex has even degree—indeed, a representation of a graph as a union of simple cycles may be obtained from an Euler tour by repeatedly splitting the tour into smaller cycles whenever there is a repeated vertex. Further, Veblen’s Theorem [1912] states that the edge set of a finite graph can be written as a union of disjoint simple cycles if, and only if, every vertex has an even degree, which also applies to disconnected graphs, and can be generalized into infinite graphs in which every vertex has finite degree [Sabidussi, 1964].

As discussed in Chapter 3, different from the often-implied condition of simple graph, the SVN is generally a multigraph where multiple edges are permitted to reflect the fact that one stakeholder may have multiple needs (even for the same type of resources, viz., political, information, goods/service, and financial) fulfilled by another stakeholder. More importantly, the requirement of simple cycle in the SVN analysis also has realistic meaning: First, the system model in the SVN analysis is static and therefore the dynamic process of value accumulation, which can be the format of visiting a stakeholder multiple times, will not be considered; Second, based on the Social Exchange Theory (SET), a simple cycle represents the standard form of Generalized Exchange and has been taken as the basic units to measure the impacts of stakeholder relationships in the network—any value cycle with a stakeholder visited more than once can be actually interpreted as the combination of several simple cycles—if it is allowed to visit a stakeholder multiple times, some simple cycles will be counted more than others, and obviously there is no point to do so. In addition, if one is interested in the question whether a specific SVN can be represented by a union of disjoint value cycles, the Veblen’s Theorem stated above is clearly applicable.

5.2.1.2 Complexity Analysis and Algorithm Choice

As discussed above, using the language of graph theory, the essence of the SVN analysis is to enumerate all the simple cycles in a weighted multidigraph under certain constraints, such as passing through a pre-selected vertex (viz., the focal organization) and obeying the pre-defined rules for edge connection (viz., internal assets within stakeholders).

According to Johnson [1975, p. 77], there are two enumeration problems on sets of objects—one is called “Counting” with the purpose of determining how many objects there are in the set, and the other is called “Finding” with the purpose of constructing every object in the set exactly once—it is obvious that the enumeration problem in the SVN analysis belongs to the “Finding” category.

A following literature review suggests that simple cycle enumeration is a classic problem with many applications in circuit theory, control theory, and communication systems [Danielson, 1968; Johnson, 1975; Szwarcfiter and Lauer, 1976; Tarjan, 1972], where simple cycle is also called the “elementary cycle” or “elementary circuit”. Weinblatt [1972, pp. 43-44] once summarized: “In many applications of directed graph theory, it is desired to obtain a list of the cycles of the graph. This information can then be used: (a) to help break the feedback paths (of a control system, a logical network, a computer program, etc.); (b) as part of a sophisticated system for optimizing computer programs; or (c) to perform more general types of analysis on computer programs, such as estimation of running times.”

Specifically, there are three major algorithms arising from the above applications for the enumeration of simple cycles in a directed simple graph:

- **Johnson [1975] Algorithm:** Using the backtrack search [Floyd, 1967] to generate all the paths of the graphs and then identifying if it is a simple cycle.
- **Danielson [1968] Algorithm:** Using the k -time multiplication (ordinary matrix product) of DSM to find the simple cycles with a length of k .
- **Cartwright and Gleason [1966] Algorithm:** Using the edge-digraph to obtain the simple cycles with the same length step by step, based on the one-to-one correspondence between the simple cycles of the original digraph and its edge-digraph.

Note that there are many variants from the methods applied in the above three algorithms, and for simplicity, only the most representative ones are listed. For these algorithms, their

time bound and space bound are summarized in Table 5-1 for a brief complexity analysis, where “ n ” is the number of vertices, “ e ” is the number of edges, and “ c ” is the number of simple cycles.

Table 5-1: Three Algorithms for Simple Cycle Enumeration in Directed Simple Graph
 [Adapted from Mateti and Deo, 1976, p. 97]

Simple Cycle Enumeration Algorithm	Time Bound	Space Bound	Method Applied
Johnson [1975]	$(n + e)c$	$n + e$	Backtrack
Danielson [1968]	$n(\text{constant})^n$	$n(\text{constant})^n$	DSM Multiplication
Cartwright and Gleason [1966]	$n(\text{constant})^n$	$n(\text{constant})^n$	Edge-digraph

From the above table, we observe that the Johnson algorithm has a manageable space bound, compared to other two algorithms. However, a manageable time bound is more desired nowadays as the major measurement for algorithm complexity, because for a single computer, the accessible memory of a program is already constrained by the digit characteristics (32-digit or 64-digit) of operation systems, although parallel computation involving multiple computers is a possible way to improve. Comparing the time bound of these three algorithms, it is not straightforward to conclude which one is the best, and therefore we take a complete graph with n vertices (loops not allowed) as the benchmark to quantitatively compare their time bound listed in Table 5-1, in light of the deterministic relationships between n , e , and c in complete graphs (see Equations 5-1 and 5-2):

$$e = \frac{n(n-1)}{2}$$

(Equation 5-1)

$$c = \sum_{i=1}^{n-1} \binom{n}{n-i+1} (n-i)!$$

(Equation 5-2)

Based on Equations 5-1 and 5-2, the comparison of the time bound of Johnson and other two algorithms is shown in Figure 5-1. Note that in the time bound for the Danielson as well as Cartwright and Gleason algorithms (see Table 5-1), there is a constant determined by the graph itself—for simplicity, a few possible values have been chosen to make the comparison of time bound easier.

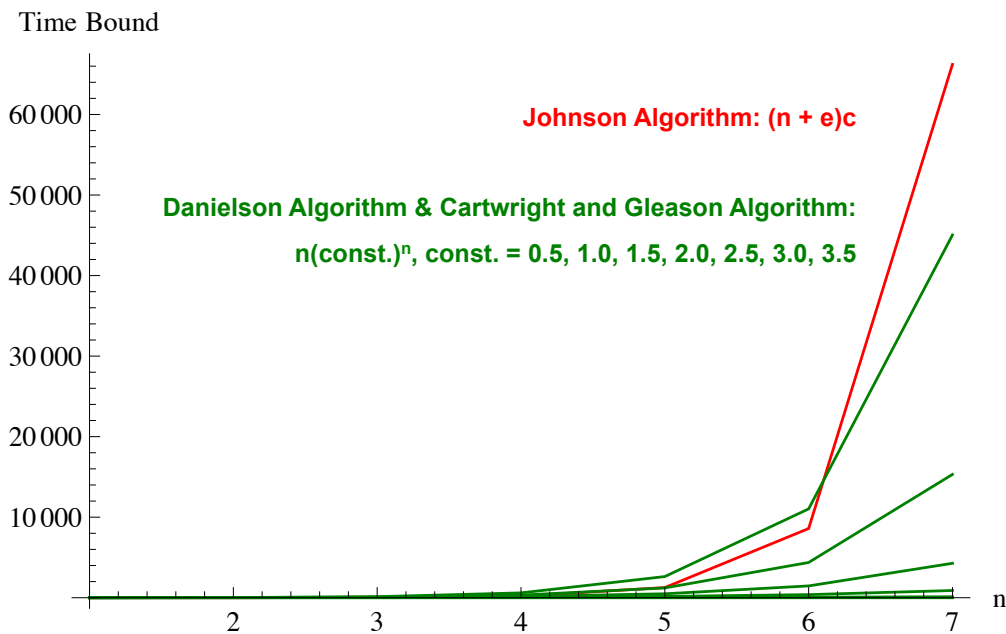


Figure 5-1: Comparison of the Time Bound between Johnson and Other Two Algorithms

From the above figure, we conclude that the Johnson algorithm is not as efficient as other two algorithms, because its time bound increases with the size of the graph much faster. In addition, as discussed before, the unique structural features associated with the DSM multiplication, which is the key operation applied in the Danielson algorithm, provide more convenience and flexibility for the network analysis—for example, compared to the Johnson as well as Cartwright and Gleason algorithms, it is much easier to extend the application of the Danielson algorithm from directed simple graph to multidigraph (viz., the SVN)—more details are followed in the next Section. Mainly for these two reasons, we choose the Danielson algorithm, or the multiplication of the DSM, as the mathematical foundation for the new modeling platform of the SVN analysis.

5.2.2 Construction of the DSM Modeling Platform

After choosing the Danielson algorithm, or the DSM multiplication, as the mathematical foundation, there is still significant work remaining for the construction of the new modeling platform: First, the algorithm needs to be adapted for multidigraph or the SVN; Second, many details regarding to software design need to be considered before the new modeling platform can be used for the SVN analysis effectively and efficiently. In light of our focus in strategic management, only the adaption of the algorithm is briefly discussed here, while the details about the corresponding software, such as its architecture, sample codes, and memo, are all documented in the Appendix¹⁹.

Specifically, centered on the adaption for the SVN analysis, this section explores the representation, algorithm, and benefits of the DSM modeling platform. Figure 5-2 shows a simplified example of the SVN used throughout the discussion. In this example, a, b, c, d, e, f, g, and h are eight value flows between four stakeholders A, B, C, and D, which is clearly a multidigraph according to the previous definition.

¹⁹ The executable Java code of the DSM modeling platform can be downloaded from <http://systemarchitect.mit.edu/docs/SVNcode.zip>, together with an instruction manual for the SVN analysis <http://systemarchitect.mit.edu/docs/SVNmanual.pdf>. This software package was developed with the collaboration from Yuan MEI at the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL), and is currently in the application process for a U.S. patent protected by the relevant laws and regulations.

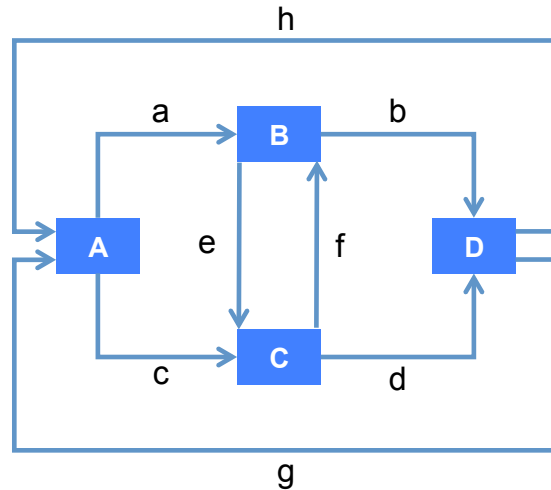


Figure 5-2: Example for the SVN (Network Representation for M)

5.2.2.1 Representation

The DSM [Browning, 1998; Eppinger et al., 1990, 1994; Steward, 1981a, 1981b] is a simple but powerful tool to model, visualize, and analyze the dependencies among system entities. Originated from the field of product design and development [Ulrich and Eppinger, 2011], DSM has been widely applied to manage the complexity of many different systems, including the modeling for indirect dependencies and dependency propagation [Keller, 2007; Lindemann, et al., 2008]. Meanwhile, it is interesting to find that the technique of modeling with matrices has also seen applications in the Social Network Analysis (SNA) since 1970s [Lorrain and White, 1971]—sociologists gave this technique a different name, that is, “blockmodeling”, which began with “weakening and extending the algebraic concept of ‘structurally equivalent’ actors in a network” [White, Boorman, and Breiger, 1976, p. 739]. However, similar to most work in the Social Network Analysis (SNA), blockmodeling is not able to model the interaction between multiple types of relationships in an interorganizational network, or in other words, it is only intended for simple graph applications.

Consistent with the original purpose of the Danielson algorithm, simple graph can be easily represented with the DSM—all the vertices are numbered as rows and columns of a matrix, and the elements (0 or 1) in the matrix show whether there is a directed edge

from row vertex to column vertex. But in order to represent the multidigraph or the SVN, two modifications need to be made for traditional DSM: First, defining the matrix elements as characters to name edges (or as 0 if there is no edge); Second, using the “addition” operation to connect the names of multiple edges with the same source and target vertices. With these modifications, the following DSM (see Figure 5-3) represents the SVN shown in Figure 5-2:

	A	B	C	D
A		a	c	
B			e	b
C		f		d
D	g+h			

Figure 5-3: DSM Representation for M

For example, the element (4, 1) in M is “g + h”, which means there are two directed edges (viz., value flows) “g” and “h” from Vertex “4” to “1” (viz., from Stakeholder “D” to “A”), in Figure 5-2. Note that all the diagonal elements (i, i) in M must be zero, because loops are not allowed in the SVN as discussed before. In addition, it is worthwhile to point out that the modified DSM in this dissertation is similar to a few concepts in other scholarly work, such as the modified Variable Adjacency Matrix [Danielson, 1968], N-Matrix [Paz, 1967], and the Reachability/Visibility Matrix [Warfield, 1973].

5.2.2.2 Algorithm

Multiplying M by itself once (ordinary matrix product), the resulting new DSM (see Figure 5-4) is:

	A	B	C	D
A		cf	ae	ab+cd
B	bg+bh	ef		ed
C	dg+dh		fe	fb
D		ga+ha	gc+hc	

Figure 5-4: DSM Representation for M^2

By observation, we conclude that the element (i, j) in the new DSM represents all the paths (viz., value paths) from Vertex (viz., Stakeholder) “i” to “j” with path length equal to 2. Particularly, the diagonal elements (i, i) in the new matrix may not be zero, because now they represent all the value cycles with a length of 2 (viz., Restricted Exchange in the form of “ $A \Leftrightarrow B$ ”) for Stakeholder “i”. This conclusion can be generalized to the k -time multiplication ($k \leq n$, the total number of vertices) of the modified DSM. For example, when $k = 3$, the corresponding DSM (see Figure 5-5) is:

	A	B	C	D
A	abg+abh+cdg+cdh	aef	cfe	cfb+aed
B	edg+edh	bga+bha	bgc+bhd+efe	efb
C	fbg+fbh	dga+dha+fef	dgc+dhc	fed
D		gcf+hcf	gae+hae	gab+hab+gcd+hcd

Figure 5-5: DSM Representation for M^3

Therefore the multiplication of the modified DSM can be applied as the basic algorithm to model the value propagation in the SVN, which in fact is to search for all the simple cycles for a focal organization and also calculate the utility scores of these cycles. Additionally, in order to accommodate the specific requirements of the SVN analysis, the following four important features have been integrated into the DSM modeling platform: “Simple Path Only”, “Connection Constraints”, “Path Score Calculation”, and “All the Value Paths”.

Simple Path Only

As highlighted earlier in this chapter, the central task of the SVN analysis is to find all the simple paths in the stakeholder network, and therefore the DSM modeling platform should filter out the non-simple paths (see the circled elements in Figure 5-5 for example) and only keep those simple ones. The requirement of “Simple Path Only” can be met by satisfying the condition that no vertex in the path has input/output degrees (viz., the number of edges incident to that vertex) greater than 2, when connecting two paths/edges. Meanwhile, this requirement also explains the condition of “ $k \leq n$, the total number of vertices” listed above, because the longest length of the simple paths/cycles in a multidigraph equals the total number of vertices—these longest simple paths/cycles are often called the “Hamiltonian paths/cycles” by operations researchers [Danielson, 1968, p. 294].

Connection Constraints

To ensure that the connections between edges (viz., value flows) are reasonable, appropriate constraints between each stakeholder’s input and out flows should be satisfied, and these constraints are actually the “internal assets” within stakeholders, as discussed in Chapters 3 and 4 (see Figure 4-15 for example). Specifically, the DSM modeling platform reads all the connection constraints as the initial inputs, in the format of listing the connectable outputs for a specific input. And then an “edge constraint check” is conducted during each time when two paths P1 and P2 are to be connected: The

last edge of P1 is checked against the first edge of P2 to determine whether they are connectable. In order to perform the task of edge constraint check more efficiently, a Hash Map is maintained by the DSM modeling platform to record all the connectable information—if the paths/edges are not connectable, the resulting path/cycle will be dropped before running the next multiplication. Note that in computer sciences, a Hash Map [Corman et al., 2001, p. 221-252; Gonnet, 1984; Knuth, 1973; Luhn, 1953] is a data structure that uses a hash function to map identifying values, known as keys, to associated values, and by doing this, its major advantage over other data structures is speed, which is even more apparent when the number of entries becomes large.

Path Score Calculation

In order to calculate the utility scores of value paths at the same time, the DSM modeling platform reads the value flows and their scores together as the initial inputs. And then, the computation for path score is finished in parallel with the generation of that path by multiplying the DSM. In addition, for the purpose of improving the computational efficiency, all the previous paths/cycles and their scores are stored in the DSM platform so that the score for a new path/cycle can be obtained from the score of two existing paths/edges forming that new path/cycle.

All the Value Paths

As discussed before, the k -length value cycles for a focal stakeholder “ i ” will be exactly represented by the diagonal element (i, i) in the resulting DSM after k -time multiplication ($k \leq n$, the total number of stakeholders). In order to find all the value cycles for that stakeholder, which constitute the sample space for the subsequent SVN analysis, the DSM platform adds all the diagonal element (i, i) together, from the initial DSM representing the network itself to the last DSM obtained after n -time multiplication.

In summary, with the above four features integrated into its algorithm, the DSM modeling platform is successfully constructed for searching, storing, computing, and

analyzing all the simple paths between any two vertices in a weighted multidigraph. Specifically, all the simple cycles (viz. value cycles) for a pre-selected vertex (viz., the focal organization) are taken as the sample space for network statistics measuring both the exchange and structural properties of the SVN, as demonstrated in Chapters 3 and 4.

5.2.2.3 *Benefits*

After running numerous and rigorous tests for the DSM modeling platform (software architecture, sample codes, and memo are documented in the Appendix), the following three major benefits of the DSM platform are confirmed:

- **Computational Performance:** Although the simple cycle search is an NP-hard problem (viz., No-Polynomial Hard Problem, definition see Corman et al. [2001, p. 986]) by nature, the DSM multiplication algorithm is very efficient for most cases in which the SVN analysis has been applied, especially after a few algorithmic improvements such as the Hash Map to optimize the usage of computer memory during calculation.
- **All-at-Once:** After n -time multiplication of the initial DSM (n is the total number of stakeholders), all the simple paths (viz., value paths) between any two vertices (viz., stakeholders) can be obtained simultaneously. This useful feature associated with matrix structure and operation brings more flexibility and convenience for the SVN analysis, as shown later in this section when revisiting the RuSakOil case.
- **Strategic Implication:** First, for the diagonal elements in the resulting DSM, each element represents the sample space for a Focal Organization, which can be used to interpret the implications for that organization, while all the diagonal elements together represent the sample space that can be used to interpret the implications for the Whole Network, which are discussed later in this chapter as an important development of the SVN analysis. Second, for the off-diagonal elements in the resulting DSM, Element (i, j) represents the influence (viz., value paths) from Stakeholder “i” to Stakeholder “j”, and further Element (i, j) and

Element (j, i) represent the relationship balance between Stakeholders “i” and “j”, which are discussed extensively through the Issue Networks in Chapter 4. These implications are explained below (see Figure 5-6) with the same example in Figure 5-2 (non-simple paths have been filtered out):

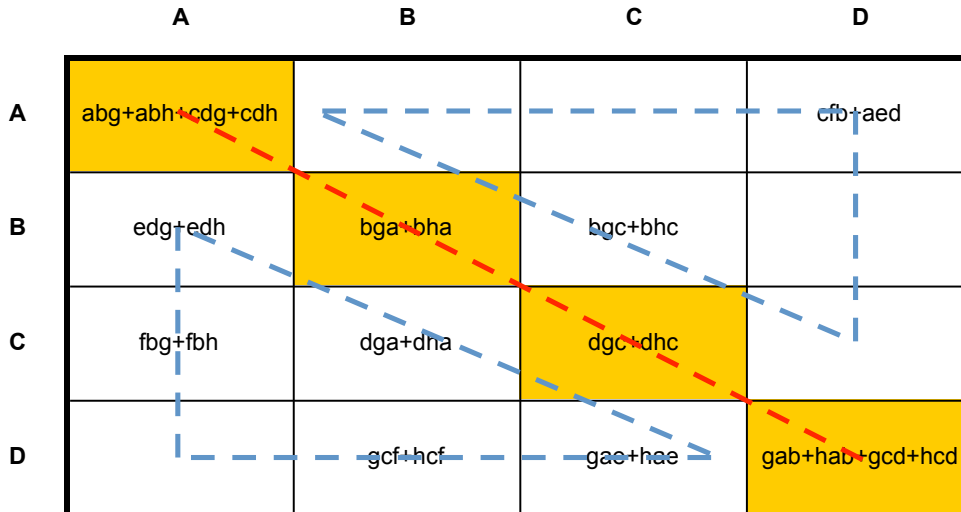


Figure 5-6: DSM Representation for the Implications of M^3

5.2.2.4 Comparison between DSM and OPN

Based on the numerous tests for the DSM modeling platform, we observe that compared to the OPN platform, the major advantage of the DSM platform is better computational performance in terms of both the running speed and the network size these platforms can handle.

There are three important factors responsible for such an advantage: First, the DSM platform is built upon the modified Danielson algorithm, which has a manageable time bound as concluded in the previous complexity analysis (see Figure 5-1), while the mathematical foundation for the OPN platform remains unclear and may have not been optimized for the SVN analysis (viz., simple cycle search in multidigraph); Second, the DSM platform integrates a few algorithmic improvements such as the Hash Map to optimize the usage of computer memory during calculation; Last but not least, the DSM platform dismisses the visualization feature (see Figure 3-12 ~ 3-14 and Figures 4-13 ~ 4-

14) for the SVN and the corresponding modeling process to save more memory on single computers, although the visualization is an attracting feature for the OPN platform to showcase the SVN analysis with small networks.

5.2.3 RuSakOil Case Revisited

After the successful construction of the DSM platform, the simplified RuSakOil case (see Figure 3-3) in Chapter 3 is briefly revisited here to better understand the forms and benefits of this new modeling platform for the SVN analysis.

First of all, the left DSM in Figure 5-7 represents the qualitative model of the RuSakOil case by showing the number of value flows from column stakeholders to row stakeholders. Meanwhile, the right DSM in the same figure shows the total utility score of value flows from column stakeholders to row stakeholders, which is calculated with the answers to the stakeholder questionnaire and provides the inputs for the subsequent quantitative model for the RuSakOil case.

By virtue of the DSM platform, the left DSM in Figure 5-8 summarizes the number of all the value paths between any two stakeholders, while the right DSM in the same figure lists the total utility score of those paths. The diagonal elements in these DSM, as discussed before, can be taken as the sample space to study the strategic implications from either the Focal Organization's perspective or the perspective of the Whole Network. In addition, two off-diagonal elements located in symmetric positions reflect the relationship balance between two stakeholders. More importantly, it is clear that with the DSM platform, the value paths between any two stakeholders can be obtained "all-at-once"—recalling similar results in the Project Phoenix case (see Table 4-2), it takes much more efforts (196 times vs. once) for the OPN platform to obtain the same amount of information about the SVN.

	pro	ent	hcc	inv	con	sup	hcg	loc	ngo
Project: pro	3	2			1	1	2	1	
Enterprise: ent	2		1	1					
Host-Country Corporation: hcc	1					1			
Investors: inv		1							
Consumers: con		1							
Suppliers: sup	1								
Host-Country Government: hcg	1	1	1				1		
Local Community: loc	2						1		
NGO: ngo								1	

	pro	ent	hcc	inv	con	sup	hcg	loc	ngo
Project: pro	1.6	1.2			0.4	0.4	1.2	0.4	
Enterprise: ent	1.2		0.8	0.4					
Host-Country Corporation: hcc	0.2					0.2			
Investors: inv		0.2							
Consumers: con		0.4							
Suppliers: sup	0.4								
Host-Country Government: hcg	1.0	0.5	0.5				1.0		
Local Community: loc	1.2						0.2		
NGO: ngo								0.4	

Figure 5-7: DSM for the Qualitative Model (Left) and the Inputs of the Quantitative Model (Right)

	pro	ent	hcc	inv	con	sup	hcg	loc	ngo
Project: pro	43	9	6	9	9	1	6	6	1
Enterprise: ent	2	20	12	1	1	2	12	12	2
Host-Country Corporation: hcc	6	17	17	17	17	6	5	14	6
Investors: inv	2	1	12	1	1	2	12	12	2
Consumers: con	2	1	12	1	1	2	12	12	2
Suppliers: sup	1	9	6	9	9	1	6	6	1
Host-Country Government: hcg	6	13	11	13	13	6	30	13	6
Local Community: loc	6	19	13	19	19	6	7	25	6
NGO: ngo	6	19	13	19	19	6	7	1	6

	pro	ent	hcc	inv	con	sup	hcg	loc	ngo
Project: pro	6.2	2.1	1.5	1.6	0.8	0.4	0.9	2.0	0.4
Enterprise: ent	1.2	2.8	1.8	0.8	0.4	0.5	1.1	2.4	0.5
Host-Country Corporation: hcc	0.8	1.2	1.1	1.0	0.5	0.3	0.3	1.0	0.3
Investors: inv	0.2	0.2	0.4	0.2	0.1	0.1	0.2	0.5	0.1
Consumers: con	0.5	0.4	0.7	0.3	0.2	0.2	0.4	1.0	0.2
Suppliers: sup	0.4	0.8	0.6	0.7	0.3	0.2	0.4	0.8	0.2
Host-Country Government: hcg	2.9	4.2	3.9	3.3	1.7	1.2	2.6	3.3	1.2
Local Community: loc	1.5	2.8	2.2	2.2	1.1	0.6	1.0	3.1	0.6
NGO: ngo	0.6	1.1	0.9	0.9	0.4	0.2	0.4	0.4	0.2

Figure 5-8: DSM for the Unweighted (Left) and Weighted (Right) Outputs of the Quantitative Model

Note that for all the DSM in Figures 5-7 and 5-8, the focal organization, market stakeholders, and nonmarket stakeholders are differentiated with the same color-coding system as Chapters 3 and 4.

5.2.4 Beyond the Computational Capacity

Although the above DSM modeling platform is very efficient for most cases in which the SVN analysis has been applied until today, simple cycle enumeration (for either simple graph or multigraph) is inherently an NP-hard problem, as highlighted by Tarjan [1972, p. 1]: “In some cases the number of objects may grow exponentially with the number of vertices in the graph; thus there are no algorithms with time bounds polynomial in the size of the graph for solving such problems. Examples include enumerating the elementary circuits, the spanning trees, or the cliques of a given graph.”

For the possible situation when the SVN is too large to be solved even with the DSM platform, we propose to add the constraint of **maximum length of value cycles** as a useful and justifiable modeling technique, which helps obtain good approximations for important network statistics in a timely manner and without enumerating all the value cycles or generating the whole sample space in the stakeholder networks.

The proposal for the above technique is based on an interesting observation from various applications of the SVN analysis: Network statistics, such as the WSO (Weighted Stakeholder Occurrence), will change with the size of the sample space by finding more value cycles with longer length in the network; However, their values do not change too much and tend to become stable after the maximum cycle length exceeds a small number (around six).

Taking the Project Phoenix case (see Figure 4-3) as an example, which has a sample space (see Figure 4-16) large enough for making observations, Figure 5-9 records the changes of the WSO for each stakeholder with the maximum length of value cycles as well as with the total number of value cycles in the sample space. Note that PP is excluded from the list of stakeholders, as the WSO of the focal organization always equals to 1 by definition (see Equation 3-3). In addition, with the DSM modeling platform, the relationships between the WSO of each stakeholder and the maximum cycle length as well as the size of the sample space can be easily obtained by increasing the multiplication times of the DSM one by one.

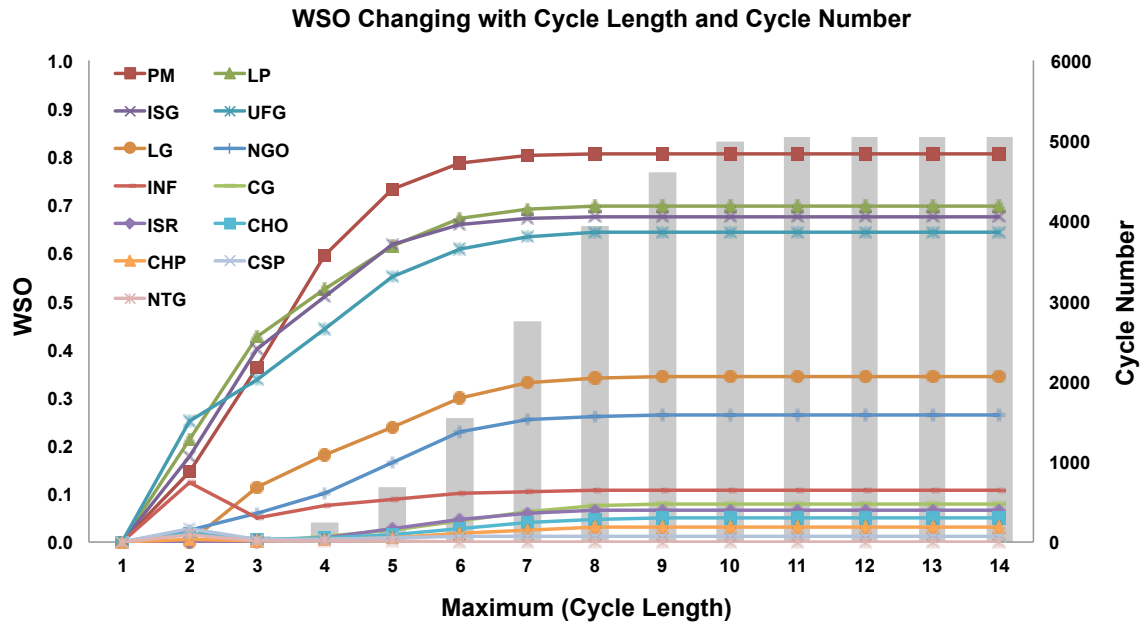


Figure 5-9: WSO Changing with Cycle Length and Cycle Number in the Project Phoenix Case

From the above figure, a few key findings are made as below:

- When the maximum cycle length (x axis in Figure 5-9) increases from one to five, the WSO of each stakeholder (color dotted lines in Figure 5-9) experiences significant changes (either increase or decrease), and the total number of value cycles (grey bars in Figure 5-9), or the size of the sample space, also sees significant change (increase only);
- When the maximum cycle length increases from six to ten, the WSO of each stakeholder becomes stable, in terms of both absolute and relative values, while the size of the sample space still sees significant change (increase only);
- When the maximum cycle length increases from eleven to fourteen, both the WSO of each stakeholder and the size of sample space become stable, in terms of both absolute and relative values;
- Comparing the above three observations, we find the correlation between the WSO and the maximum cycle length is stronger than that between the WSO and the size of sample space, because longer value cycles tend to have smaller utility scores (under both the “*abc*” and “*abc*²” rules) and therefore contribute less to the

WSO, even the number of those longer cycles can increase significantly; In addition, the WSO is influenced by the maximum cycle length through the changes of both exchange and structural properties of the SVN at the same time.

Based on the above findings, we conclude that adding the constraint of maximum cycle length is a useful technique to obtain good approximations for network statistics without enumerating all the value cycles in the SVN. Further, the rationale behind this technique can be justified from at least three aspects:

- From the perspective of the focal organization, the maximum length of value cycles reflects the difficulty level for the organization to engage its stakeholders in an indirect way;
- From the perspective of other stakeholders, the maximum length of value cycles reflects the cognitive boundary for these stakeholders to realize they are involved in an indirect value exchange;
- From a more holistic perspective, the maximum length of value cycles reflects the possibility for both the focal organization and its stakeholders to participate in a generalized exchange as well as to maintain such an exchange with mutual trust and social contracts against the problem of free-riding.

In fact, the above three justifications also suggest three promising directions respectively, to further integrate the SVN analysis with other academic fields in future research:

- In the field of stakeholder theory, it is important for firms and their managers to understand how to define the stakeholder salience [Mitchell, Agle, and Wood, 1997] from a relational perspective and also factor in the impacts of indirect relationships [Rowley, 1997];
- In the field of social psychology, it is important for individuals and organizations to understand how to identify the maximum distance [Harary, Norman, and Cartwright, 1965; Jackson, 2008] to communicate with each other and trace the received utility with their constrained cognitive capacity;

- In the fields of exchange networks and social dilemma, it is important for individuals and organizations to understand how to avoid the free-riding problem in the situation of generalized exchange [Yamagishi and Cook, 1993], possibly with the help of network game theory [Myerson, 1977] and the stag hunter games [Skyrms, 2004].

Arguably the potential findings from these three directions can all deepen the knowledge in strategic management for the practical implementation of generalized exchange as an effective stakeholder strategy, and therefore both theoretical and empirical research in each direction are much desired.

5.3 Development: from Focal Organization to Whole Network

Based on the previous work in Chapters 3 and 4, which mainly explore the implications of the SVN from the perspective of a pre-chosen focal organization, this section provides the methodological support to further explore the implications of the SVN from the perspective of the whole network. In the Whole Network analysis, a new family of network statistics is constructed from an expanded sample space, which includes all the non-duplicate value cycles in the SVN, so that the stakeholder importance and other network measurements can be evaluated in a more holistic view. With these more holistic network measurements, as well as the additional computational resources provided by the DSM modeling platform, it is possible to bring forward a few principles for hierarchical modeling in the SVN as an important extension of the Whole Network analysis.

5.3.1 Motivation for A More Holistic View

As discussed in Chapter 2, in recent research of Stakeholder Theory, there have been a few proposals [Lucea, 2007; Mahon, Heugens, et al., 2003; Rowley, 1997] for applying the network approach from social sciences, especially the Social Network Analysis (SNA), to overcome the limitation of the traditional “Hub-and-Spoke” Model and study

the networked relationships between stakeholders. We argue that, however, an inherent methodological difference between Stakeholder Theory and the Social Network Analysis (SNA) has not yet received enough attention: For Stakeholder Theory, by definition [Freeman, 1984, p. 46], a focal organization and its objectives always come at the first place, and then the stakeholders are identified by the criterion of whether they “can affect or is affected by the achievement of the organization’s objectives.” Although later on more rigorous theories, such as the “stakeholder salience” [Mitchell, Alge, Wood, 1997], have been developed to better identify “who and what really counts”, it is still necessary to select a focal organization before everything else; By contrast, in the Social Network Analysis (SNA), the requirement for such a focal actor does not exist (except the special case of the “ego-centered” networks, which “have been widely used by anthropologists to study the social environment surrounding individuals (Boissevain, 1973) or families (Bott, 1957)” [Wasserman and Faust, 1994, p. 42]), and on the contrary, one main purpose of the Social Network Analysis (SNA) is to find who is the focal actor in a network by virtue of the structural measurement of “centrality” (see Table 2-3)—as put forward by Wasserman and Faust [1994, pp. 42-43], “a social network arises when all actors can, theoretically, have ties to all relevant actors”, and therefore “the primary object of study” in the Social Network Analysis (SNA) is “this complete collection of actors (one or more sets) and the ties among them.”

Also rooted in the network approach from social sciences, the SVN analysis in this dissertation develops a multi-relational network model as an improvement over the traditional “Hub-and-Spoke” Model, and then defines generalized exchange as the basic units to measure the exchange and structural properties of such a network. Through taking the impacts of indirect stakeholder relationships into consideration, the SVN analysis provides a more comprehensive and therefore more accurate way to measure interesting network properties, such as the stakeholder importance or the WSO, which has been validated in Chapter 4 with the Project Phoenix case.

However, similar to other research in Stakeholder Theory, SVN analysis also requires the choice of a focal organization at the very beginning. The above contrast between

Stakeholder Theory and the Social Network Analysis (SNA), in terms of whether or not requiring a focal organization/actor, motivates us to also analyze the SVN from the perspective of the whole network, instead of one single perspective of a pre-chosen focal organization, in order to gain a deeper and more holistic appreciation for the properties of the SVN.

For better understanding of the difference between these two perspectives, a simplified SVN is shown as an example in Figure 5-10:

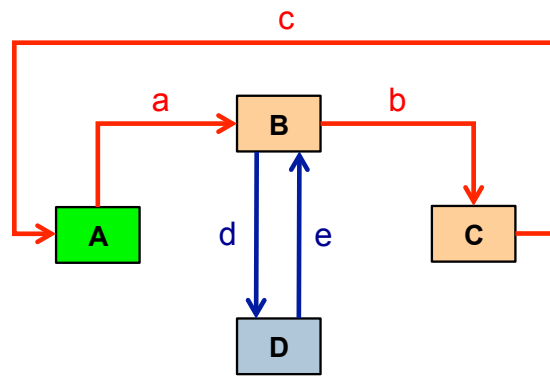


Figure 5-10: Example SVN Showing the Difference between Two Perspectives

In the above example, if taking A as the focal organization, it is apparent that B and C are equivalently important from A’s perspective, because in the SVN there is only one simple cycle consisting of “a”, “b”, and “c” for the focal organization A, and based on Equation 3-3, the WSO of B and C are the same. However, if examining their relationships from the perspective of the whole network, another simple cycle consisting of “d” and “e” emerges immediately—because this cycle does not pass through A, it has been missed in previous analysis from the focal organization’s standpoint—but also because of this cycle, compared to C, B is able to extract additional resources from D, which can be important to fulfill A’s needs directly or indirectly, and therefore we argue that the importance of B should not be treated equally to C, if a more holistic view is taken by including those value cycles not passing through the focal organization.

In light of the above example, we further argue that it is beneficial for the SVN analysis to move its analytical perspective from a focal organization to the whole network, because by counting in all the value cycles in the SVN, the exchange and structural properties of such a multi-relational network can be better measured with a more holistic view. As a return, these more holistic measurements should be able to enhance the descriptive accuracy of the SVN analysis and also supply this method with more instrumental power—these benefits are validated in the end of this section by revisiting the Project Phoenix case.

In addition, as proposed in Chapter 4, it is desired to be able to model the complicated organizational hierarchies within large stakeholders. Following this proposal, we argue the network measurements from the perspective of the whole network are less biased than those from the perspective of the focal organization, and therefore should be taken as the primary basis to identify large and important stakeholders in the SVN. Once those stakeholders are identified, as demonstrated by the case study of China’s Energy Conservation Campaign in Chapter 6, more computational and analytical resources can be allocated to model their internal structures, from which more fine-grained decisions are possible to be made accordingly.

Before proceeding to the details of the Whole Network analysis, a methodological caveat should be given regarding to the limitation of the SVN approach: Moving from the traditional “Hub-and-Spoke” Model to the SVN Model, as well as from the perspective of a focal organization to the perspective of the whole network, we continuously advance the frontier of the SVN analysis through gradually integrating the network approach from social sciences with Stakeholder Theory. However, the inherent difference discussed previously between stakeholder theory and the network approach cannot be completely avoided in the SVN analysis, mainly because at the very beginning of the whole analysis, all the data and information still have to be collected around a pre-chosen focal organization, which is the starting point of stakeholder theory and determines the egocentric nature of all the SVN models. In other words, the SVN model built around a focal organization aims to reduce the egocentric bias and understand the stakeholder

network as a whole, but the network itself will not necessarily be the same as it would have been if another stakeholder had been taken as the focal organization.

5.3.2 Upgrades of the DSM Modeling Platform

Based on the above motivation, the Whole Network analysis takes all the value cycles in the SVN as the sample and then constructs a new family of network statistics to provide more holistic and less biased measurements for the properties of the network. However, in order to compute the new statistics for the whole network, it is necessary to make a few upgrades for the DSM modeling platform.

5.3.2.1 Computing the Expanded Sample Space

The DSM modeling platform should be able to compute network statistics for the expanded sample space, which includes all the value cycles in the SVN. Each diagonal element in the resulting DSM represents the value cycles passing through that stakeholder (see Figure 5-6), and therefore the sum of all the diagonal elements should represent all the value cycles in the SVN, except the duplicate ones added as different permutations of the same value cycle. Still taking Figure 5-6 as an example, in the sum of all the diagonal elements, value cycle “abg” has other two permutations of “bga” and “gab” when B and D are treated as the focal organization respectively. It is obvious that “abg”, “bga”, and “gab” are actually the same value cycle, and further, this observation can be generalized as: The k -length value cycle has exactly k permutations in the sum of all the diagonal elements.

Arguably, in the expanded sample space, each value cycle should be counted only once and other permutations of the same cycle should be filtered out from the sum of all the diagonal elements in the resulting DSM. The main reason lies in that the difference between value cycles has already been reflected in the way their utility scores are calculated, and it does not make sense for the SVN analysis to count longer cycles more than shorter cycles in the measurements for network properties. As highlighted by

Johnson [1975, p. 77], for the enumeration problems falling into the category of “Finding”, their purpose is to construct “every object in the set exactly once.”

To do this, we propose two modeling techniques to filter out different permutations of the same value cycle so that all the non-duplicate value cycles in the SVN can be found for the Whole Network analysis:

- **Technique A:** First adding all the diagonal matrix elements together, and then identifying different value cycles of the same length with the sum code of all the edges in each cycle;
- **Technique B:** First dividing the score of each value cycle by its own length, as the k -length cycle has exactly k different permutations, and then adding all the diagonal matrix elements together.

Compared to Technique A, which is an algorithmic technique and can be integrated into software design, Technique B is more like a mathematical technique, because in fact it does not find the complete set of non-duplicate value cycles, but utilizes the unique features associated with the definitions of network statistics to bypass the check process for duplicate cycles and still be able to calculate the values of those statistics, which provide the foundation to interpret the strategic implications of the whole SVN.

Specifically, considering the benefit of finding the complete set of non-duplicate value cycles, we choose Technique A to upgrade the previous DSM modeling platform (see Software Architecture in the Appendix), while the application of Technique B is briefly discussed later in this chapter, together with another technique of collapsing multidigraph into simple graph in the Whole Network analysis.

5.3.2.2 Redefining the Value Propagation Rule

In addition to enabling computation for the expanded sample space, another important upgrade from the previous DSM platform is to switch the value propagation rule in the

quantitative SVN model from “ abc^2 ” back to “ abc ”, which is the simple multiplicative rule applied to the RuSakOil case in Chapter 3.

The redefinition of the value propagation rule is mainly based on the change of an important modeling assumption when moving the analytical perspective of the SVN analysis from a focal organization to the whole network. Recalling the utility model of generalized exchange discussed in Chapter 3 (see Section 3.4), and also as emphasized by Cameron, Crawley, Feng, and Lin [2011, p. 40]: “To solve the system, we first constrain the satisfaction of all stakeholders to zero, leaving only the organization’s satisfaction in the objective function. While mathematically convenient, this also best represents the firm’s outlook—maximize the long term profitability of the firm, where the distinction ‘long term’ is interpreted as retaining stakeholders via non-negative satisfaction.”

We observe that the previous Focal Organization analysis assumes the utilities of other stakeholders equal to zero, and obviously this assumption no longer holds in the Whole Network analysis, which aims to understand the implications of the SVN as a whole, instead of taking the egocentric view of a pre-chosen focal organization.

Therefore we argue that “ abc ” is a more appropriate rule to calculate the value propagation in the Whole Network analysis, because it reflects both the benefits (viz., the subjective utilities of each stakeholder or the value flow scores) and the costs (viz., the difficulty to manage longer cycle and the constrain of cognitive capacity) of a value cycle at the same time, and more importantly, it does not count the last value flow twice (although the number “twice” may change with different choice of the “alpha” in the utility function for generalized exchange, see Equation 3-16) to stress the egocentric standpoint of the focal organization on its own needs.

5.3.3 Whole Network Measurements and Project Phoenix Case Revisited

With the above two important upgrades, the DSM modeling platform is now ready to analyze the implications of the SVN from the perspective of the whole network.

First of all, based on the definitions of the WSO (Weighted Stakeholder Occurrence, see Equation 3-3) and WVFO (Weighted Value Flow Occurrence, see Equation 3-6) in the Focal Organization analysis, two similar network statistics are constructed from all the value cycles in the SVN to measure the relative importance of stakeholders and value flows in a more holistic way: NWSO (Network Weighted Stakeholder Occurrence, see Equation 5-3) and NWVFO (Network Weighted Value Flow Occurrence, see Equation 5-4). Similar to the WSO, we also name the NWSO as Exchange Centrality II, or Crawley Centrality II.

$$\text{Network Weighted Stakeholder Occurrence (NWSO)} = \frac{\text{Score Sum of All the Cycles Containing a Specific Stakeholder}}{\text{Score Sum of All the Cycles in the Network}}$$

(Equation 5-3)

$$\text{Network Weighted Value Flow Occurrence (NWVFO)} = \frac{\text{Score Sum of All the Cycles Containing a Specific Value Flow}}{\text{Sum (Score Sum of All the Cycles Containing a Specific Value Flow)}}$$

(Equation 5-4)

For the convenience of comparison, Table 5-2 lists the equations for the WSO and WVFO from the Focal Organization analysis, as well as for the NWSO and NWVFO from the Whole Network analysis.

Table 5-2: Network Statistics Comparison between Focal Organization and Whole Network

	Focal Organization Analysis	Whole Network Analysis
Stakeholder Importance	$\text{WSO} = \frac{\text{Score Sum of the Value Cycles Containing a Specific Stakeholder}}{\text{Score Sum of All the Value Cycles for the Focal Organization}}$	$\text{NWSO} = \frac{\text{Score Sum of All the Cycles Containing a Specific Stakeholder}}{\text{Score Sum of All the Cycles in the Network}}$
Value Flow Importance	$\text{WVFO} = \frac{\text{Score Sum of the Value Cycles Containing a Specific Value Flow}}{\text{Sum (Score Sum of the Value Cycles Containing a Specific Value Flow)}}$	$\text{NWVFO} = \frac{\text{Score Sum of All the Cycles Containing a Specific Value Flow}}{\text{Sum (Score Sum of All the Cycles Containing a Specific Value Flow)}}$

From Equations 5-3 and 5-4, we observe that the values of NWSO and NWVFO only depend on the score sum of a specific group of value cycles, which contain either a particular stakeholder or a particular value flow. Therefore, under this situation, it will

not be necessary literally “finding” all the value cycles in that specific group, and the primary task for the calculation of the NWSO and NWVFO will be “counting” the total utility scores of these value cycles (see Johnson [1975, p. 77] for the difference between “counting” and “finding” in enumeration problems, as discussed earlier in this chapter).

Based on the above observation as well as the “abc” rule chosen for the Whole Network analysis, a special technique can be devised to calculate the NWSO and NWVFO without finding all the value cycles in the SVN. As shown in Figure 5-11, this technique collapses a multigraph (vertices: A_1, B_1, C_1 and edges: $a_1, a_2, b_1, b_2, c_1, c_2$), which is the standard form of the SVN, into a simple graph (vertices: A, B, C and edges: a, b, c) by combining multiple edges into a single edge ($a = a_1 + a_2; b = b_1 + b_2; c = c_1 + c_2$), and then calculates network statistics for the simple graph, which can finally be converted back to the measurements for the original multigraph (see Equations 5-5 and 5-6 as an example).

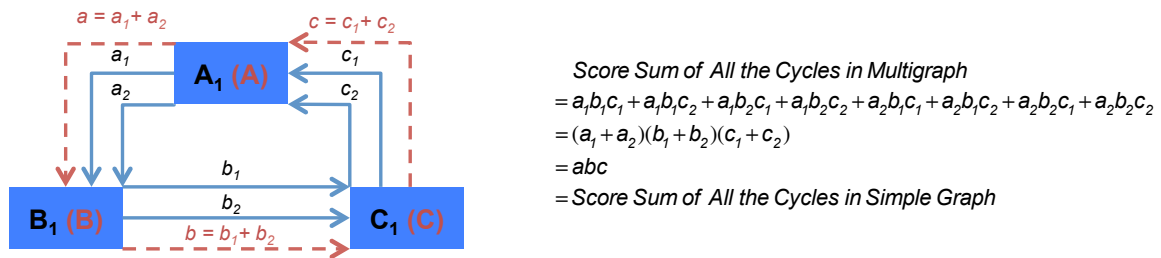


Figure 5-11: Example for the Conversion between Multigraph and Simple Graph

$$NWSO_{A_1} = NWSO_A$$

(Equation 5-5)

$$NWVFO_{a_1} = NWVFO_a * \frac{a_1}{a} = NWVFO_a * \frac{a_1}{a_1 + a_2}$$

(Equation 5-6)

As discussed before, by integrating the above technique with the Technique B for the computation of the expanded sample space, there is no need to find all the value cycles in the SVN and meanwhile the check process for duplicated cycles can also be bypassed, if

the objective of the analysis is not to identify the top value cycles with the highest utility scores. These benefits will certainly save more computational resources and speed the calculations for the NWSO and NWVFO in the Whole Network analysis. In addition, once the multigraph is collapsed, the algorithms only applicable for simple graph will then become available to improve the efficiency of the DSM modeling platform.

Now the previous Project Phoenix (PP) case is briefly revisited in the Whole Network analysis. Specifically, the NWSO of each stakeholder (including PP) is calculated with Equation 5-3 and then compared to the WSO from the Focal Organization analysis in Chapter 4. Note that the concept of the NWSO has also been applied in the SVN analysis for the Mobile Services Ecosystem [Arvind, 2009, pp. 53-57], based on our suggestion.

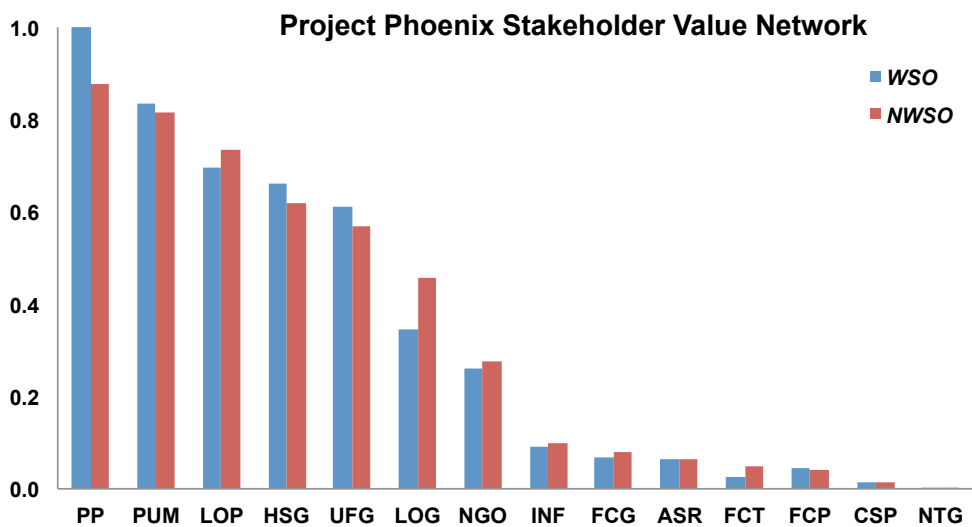


Figure 5-12: Comparison between NWSO and WSO in the Project Phoenix Case

Figure 5-12 directly compares the NWSO and the WSO of each stakeholder. We observe that, however, these two network statistics are not on the same scale, as the sample space of the Whole Network analysis is larger by adding the value cycles not passing through PP, which is the focal organization in previous analysis. In order to make such a comparison more meaningful, the values of the NWSO are adjusted from PP’s perspective—in another word, after adjustment, PP’s NWSO and WSO both equal to 1.0. The comparison between the adjusted NWSO and the WSO is shown in Figure 5-13.

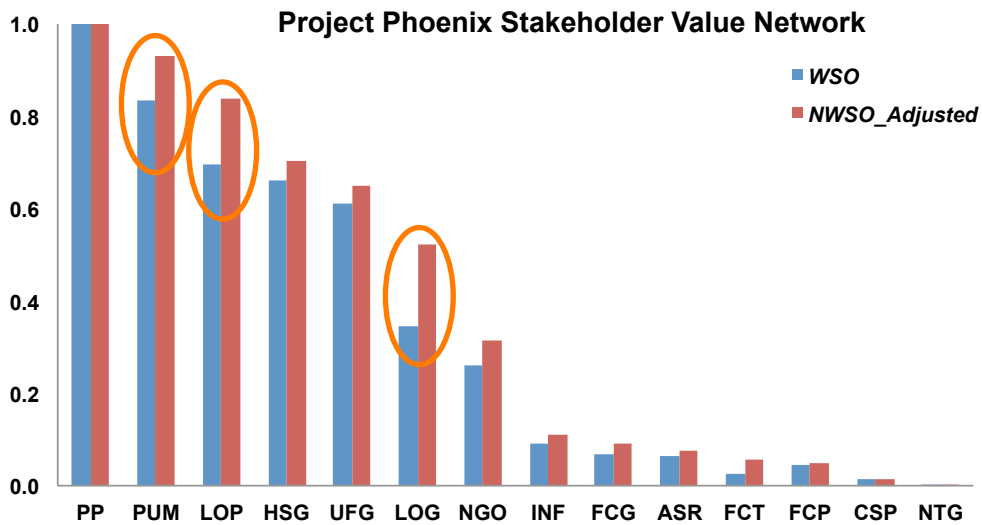


Figure 5-13: Comparison between NWSO_Adjusted and WSO in the Project Phoenix Case

From the above figure, we conclude that by including all the value cycles in the SVN—more specifically, by also considering the value cycles not passing through PP—the relative importance (for PP) of three stakeholders have seen the biggest increase, and these three stakeholders are Local Governments (LOG), Local Public (LOP), and Public Media (PUM). This conclusion is surprisingly consistent with the previous conclusion made from a similar comparison between the “Hub-and-Spoke” Model (see Figure 4-25) and the SVN model for a foal organization (see Figure 4-19). In that comparison, by adding the indirect relationships between PP and its stakeholders (viz., the value cycles passing through PP) into consideration, PUM and LOP are identified as the two most important stakeholders, and meanwhile, the relative importance of LOG has also seen the biggest increase.

For better understanding, the above conclusions are restated in a more systematic way:

- Going from the “Hub-and-Spoke” Model to the SVN model for PP, the size of sample space increases from 21 value cycles to 5039 value cycles. The additional 5018 cycles represent the generalized exchanges between PP and its

stakeholders, and the impacts of these generalized exchanges spotlight the relative importance of PUM, LOP, and LOG for PP.

- Going from the SVN model for PP as the focal organization to the SVN model for the whole network, the size of sample space increases from 5039 value cycles to 6772 value cycles. The additional 1733 cycles represent the generalized exchanges only between PP's stakeholders, and the impacts of these generalized exchanges further spotlight the relative importance of PUM, LOP, and LOG for PP.
- Based on the later developments in this retrospective case study (viz., unanticipated firestorm of protest from PUM and LOP), we conclude that the Whole Network SVN model is a significant improvement over the “Hub-and-Spoke” Model, for both exchange and structural network properties. Further, the description for the phenomena associated with network properties also becomes more and more accurate. These benefits clearly demonstrate the strength of the SVN model in understanding the impacts of networked stakeholder relationships on the long-term success of large engineering projects. In addition, as shown through the two-stage development from the Focal Organization analysis to the Whole Network analysis, the strength of the SVN approach is gradually built up by taking a more and more holistic view for the social and economic relationships between the focal organization and its stakeholders.

5.3.4 Principles for Hierarchical Modeling

Once the DSM platform is developed and new statistics for the whole network are constructed, more computational and analytical resources are now become available to model the organizational hierarchies within large stakeholders, as discussed in Chapter 4.

Before laying out the principles for hierarchical modeling and then applying them to the SVN analysis, it is an essential task to define the meaning of “hierarchy”, a fashionable word across many academic fields, such as physics, biology, engineering, social sciences, and so on. Although in each field, the definition of “hierarchy” can be very different,

Simon [1962] was arguably the first one attempting to build “a theory of hierarchy” in order to better understand and manage the complexity in social, physical, biological, and symbolic systems.

In his groundbreaking paper, “The Architecture of Complexity” Simon defined “hierarchy” in both a narrow and a broad way: Narrowly speaking, “hierarchy” refers to “a complex system in which each of the subsystems is subordinated by an authority relation to the system it belongs to” [Simon, 1962, p. 468]; By contrast, a broader definition of “hierarchy” is “a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem” [Simon, 1962, p. 468].

Specifically, based on the organizational context of the SVN analysis, we choose the above narrow definition to explore how to model the relationships between a few smaller stakeholders “subordinated by an authority relation” to a larger stakeholder they belong to. As pointed out by Simon [1962, p. 468], the narrow definition of “hierarchy” is given for the “hierarchic formal organization” often studied in social sciences, and within such an organization, “each system consists of a ‘boss’ and a set of subordinate subsystems. Each of the subsystems has a ‘boss’ who is the immediate subordinate of the boss of the system.” He also observed “business firms, governments, universities all have a clearly visible parts-within-parts structure” [Simon, 1962, p. 469].

Note that the above narrow definition of “hierarchy” is almost identical to the one used in organizational economics, where the “hierarchy” generally refers to the organizations with authorities, in contrast with the autonomous market. In fact, “hierarchies” and “markets” are often treated as two opposite but complementary choices to form organizations from the perspective of economics [Williamson, 1973, 1975, 1981].

After defining the “hierarchy”, we now propose five basic principles for hierarchical modeling in the SVN, which are organized in a logic order and also followed by a brief explanation:

- **Principle A:** *In the SVN, hierarchy is not an interorganizational, but an **intraorganizational** phenomenon.*
 - Explanation: In both engineering systems [Moses, 2004b] and strategic management [Thorelli, 1986] fields, it is a consensus that networks are non-hierarchical in principle. Therefore, defined as interorganizational networks by us, the SVN themselves are not hierarchies. In addition, according to Simon’s definition [1962, p. 468] for “hierarchic formal organization”, we treat hierarchies as intraorganizational phenomena.

- **Principle B:** *In the SVN, hierarchical modeling is not a bottom-up, but a **top-down** approach to decomposing a stakeholder into a set of subordinate ones.*
 - Explanation: First, for an organization with multiple hierarchies, the top-down approach is consistent with the nature order of human’s cognition, which always evolves from simple observations to complicated ones. Second, as a holistic network approach, starting from larger organizations and then digging into their internal structures can ensure that the SVN analysis does not miss the big picture at the first place. Last but not least, the intraorganizational relationships are generally more dynamic than the interorganizational relationships [Simon, 1962, p. 477], and therefore should be more difficult to be captured in the SVN model, which is static by nature. In another word, the top-down approach guarantees that the merits of the SVN model are first applied to analyze those more static relationships on the higher level of hierarchical model.

- **Principle C:** *In the SVN, **importance** and **necessity** are two criteria to identify the stakeholders to be decomposed on the next level of hierarchical model.*
 - Explanation: Limited by the computational and analytical resources, it is not realistic to model the detailed hierarchies within each stakeholder, and therefore those important stakeholders have the priority to be decomposed on the next level of hierarchical model to better understand and manage

their related complexities. Meanwhile, some important stakeholders may have very simple internal structures, and under this situation, it is not necessary to decompose these stakeholders to save more computational and analytical resources.

- **Principle D:** *In the SVN, NWSO is a more holistic measurement for stakeholder importance and therefore should be applied in hierarchical modeling.*
 - Explanation: As discussed in this chapter, especially demonstrated by revisiting the Project Phoenix case, we conclude that compared to WSO, NWSO is a more holistic measurement for stakeholder importance in the SVN model, and therefore should be taken as the “importance” criterion in hierarchical modeling.

- **Principle E:** *In the SVN, NWVFO is the network measurement for value flow importance and can help NWSO build the hierarchical model on the next level.*
 - Explanation: As discussed in Chapter 3, WVFO identifies the most important value flows and can be used with WSO together to manage the complexity of the SVN model. Similarly, as an alternative for WVFO, NWVFO can also be used with NWSO together in hierarchical modeling for the SVN.

Next in Chapter 6, the above five basic principles for hierarchical modeling will be discussed in more detail and also applied to a prospective case study for China’s Energy Conservation Campaign.

5.4 Chapter Summary

As a necessary preparation for better computational performance, this chapter first utilizes the Danielson [1968] algorithm for simple cycle search to build a new modeling platform—the DSM platform—as the dedicated software tool for the SVN analysis. And

then, this chapter further develops the SVN modeling framework from the Focal Organization analysis to the Whole Network analysis in two steps: First, the sample space of network statistics is expanded by including all the non-duplicate value cycles in the network; and then, a new family of network statistics is constructed to interpret the strategic implications of the SVN from the perspective of the whole network, instead of a pre-chosen focal organization.

Once the DSM platform is developed and new statistics for the whole network are constructed, more computational and analytical resources are now become available to model the organizational hierarchies within large stakeholders. Therefore, in the end of this chapter, five basic principles for hierarchical modeling in the SVN are derived as an important extension of the Whole Network analysis. In the next chapter, these principles are discussed in detail and then applied to a prospective case study for China's Energy Conservation Campaign.

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CHAPTER 6. CASE STUDY II: CHINA’S ENERGY CONSERVATION CAMPAIGN

“Hierarchy, I shall argue, is one of the central structural schemes that the architect of complexity uses.”

— Simon [1962, p. 468]

“The significant problems we face cannot be solved at the same level of thinking we were at when we created them.”

— Albert Einstein (1879~1955)

6.1 Chapter Introduction

This chapter applies the Whole Network analysis developed in Chapter 5 to study a more complicated SVN involving large stakeholders on the national scale, that is, China’s Energy Conservation Campaign. As discussed in Chapter 4 (see Section 4.3.1.1), for those large stakeholders, it is necessary to understand their internal structure before their specific needs for value exchanges can be better identified. With the DSM modeling platform and new measurements for the whole stakeholder network established in Chapter 5, more computational and analytical resources are now available to perform such an important task, viz., modeling the multi-level organizational hierarchies within large stakeholders in the SVN.

Further, Chapter 5 proposes five basic principles for hierarchical modeling in the SVN:

- **Principle A:** *Hierarchy is an **Intraorganizational** phenomenon;*
- **Principle B:** *Hierarchical modeling is a **Top-Down** approach to decompose a stakeholder into a set of subordinate ones;*

- **Principle C:** *Importance and Necessity* are two criteria to identify the stakeholders to be decomposed on the next level of hierarchical model;
- **Principle D:** *NWSO* is a more holistic measurement for stakeholder importance and therefore should be applied in hierarchical modeling;
- **Principle E:** *NWVFO* is the network measurement for value flow importance and can help *NWSO* build the hierarchical model on the next level.

Specifically, following the above principles, this chapter models the SVN of China's Energy Conservation Campaign from top to down into three different levels: On one hand, the *NWSO* and *NWVFO* calculated in a higher-level model provide more holistic measurements (than *WSO* and *WVFO*) for the most important stakeholders and value flows, which are then decomposed into subordinate stakeholders and more detailed value exchanges to form a lower-level model; On the other hand, the *NWSO* and *NWVFO* (among other measurements) calculated in a lower-level model are expected to answer interesting questions which are raised from the precedent higher-level model, but cannot be completely answered by the information and analysis of the same level.

As argued by Simon [1962, p. 468], hierarchy is “one of the central structural schemes that the architecture of complexity uses.” By modeling the multi-level organizational hierarchies of large stakeholders, we intend to explore a systematic way to manage the complexity associated with the SVN—not only better identify stakeholder needs through mapping their internal structures, but also obtain a deeper appreciation of stakeholder interactions from their value exchanges on a more detailed level. As a major extension of the Whole Network analysis, hierarchical modeling provides the basis to formulate effective strategies in order to improve the networked relationships between stakeholders and therefore instill more instrumental power into the SVN methodology, in addition to its descriptive accuracy demonstrated by the Project Phoenix case.

Before introducing the background of China's Energy Conservation Campaign, it is beneficial to highlight a few key differences between this case and the Project Phoenix

case in Chapter 4, so that the reason can be better understood why each case is chosen at different stage during the development of the SVN method:

- **Main Purpose:** The China case aims to demonstrate the instrumental power of the SVN analysis through formulating the strategies to manage stakeholder relationships, while the Project Phoenix case aims to demonstrate the descriptive accuracy of the SVN analysis through explaining the outcome from the networked stakeholder relationships;
- **Analytical Focus:** The focus of the China case is to model the organizational hierarchies of large and important stakeholders from the perspective of the whole network, while the focus of the Project Phoenix case is to explore the integration between stakeholders and strategic issues from the perspective of a focal organization in the network;
- **Temporal Boundary:** China's Energy Conservation Campaign is a prospective case which may last for decades, while Project Phoenix is a retrospective case which lasts only five years;
- **Spatial Boundary:** China's Energy Conservation Campaign is a nationwide task which may include many engineering projects among other activities, while Project Phoenix is a specific engineering project conducted at one operating facility in the United States;
- **Network Contexts:** The social, political, economic, cultural and other contexts in China and the United States are very different, and these differences will exert huge impacts on the formation of as well as the consequent analysis for stakeholder networks in these two case studies;
- **Modeling Platform:** The Project Phoenix case utilizes the OPN modeling platform, while the China case utilizes the DSM modeling platform, mainly because of different sizes of these two SVN models and the corresponding requests for computational capabilities.

6.2 Case Description and Modeling Preparation

This section first introduces China's Energy Conservation Campaign, starting with a short discussion on the challenges of energy utilization and sustainable development. After that, the motivations behind this case study as well as the preparation process for SVN models are also briefed.

6.2.1 China's Energy Challenges and the Energy Conservation Campaign

In the past thirty years, with China's rapid economic development, the whole country is also facing unprecedented challenges of energy production as well as many social, political, economic, and environmental issues related to energy utilization. These challenges can be boiled down to five major conflicts [Ni, Chen, and Li, 2008]: (1) the conflict between fast-growing energy demand and the limited capacity of energy supply; (2) the conflict between environmental protection and energy consumption; (3) the conflict between the rapid growth of demand for liquid fuel as well as the related energy security and the increasing dependency on foreign oil and gas; (4) the conflict between the energy quality required by fast urbanization as well as large rural regions and the current availability of clean energy; (5) the conflict between the need to improve China's global image and the huge economic costs associated with reducing greenhouse gas emissions. These major conflicts further put forward an urgent request for China to achieve the sustainable development in energy production and utilization, while maintaining its fast speed of economic growth and protecting the natural environment.

Specifically, as emphasized by Jiang Zemin [2008], the "core of the third generation" of China's leaders, the low efficiency of energy utilization is currently a big hurdle for China's sustainable development in energy, environment, and economy. Meanwhile, energy conservation has been proven to be one of the most practical and effective strategies to enhance the efficiency of energy utilization [Chai and Zhang, 2010; He, Deng, and Su, 2010; Jiang, Sun, and Liu, 2010; Ma, Liu, Fu, et al., 2011]. Compared to the advanced level of energy efficiency worldwide, there are still huge potentials for

China to save more energy in the utilization process and increase the energy efficiency [Wang, 2008].

In addition, energy conservation has a more far-reaching significance for the sustainable development of the whole society of China: First, as a developing country, China is still far from the completion of its industrialization and urbanization process [TSMPT, 2008], and in light of the experience of developed countries, this process has a significant path dependence [Li, Ma, Pan, et al., 2006], which means the nationwide differences of industrial structure and infrastructure mode will determine the “baseload” level of energy utilization. Thus, in the early and middle stages of the development process, implementing the strategy of energy conservation will help China avoid the “extensive pattern” of economic growth, and fulfill the goal of the “resource-saving and environment-friendly society” [Hu Jintao, 2007]. Second, the endowment of China’s primary energy resources (viz., rich coal, poor oil, and little gas), as well as the fact of coal-dominated energy supply in the long term, pose inherent difficulties for the sustainability of energy utilization in China. This situation is even worsened when climate change and energy security nowadays become two major concerns of the international community [IPCC, 2007; Yergin, 1991]. Nevertheless, it is these difficulties from both domestic and international aspects that highlight the necessity for China to take the strategy of energy conservation as one of the seven “basic national policies” [National People’s Congress, 2007].

As such, Chinese government has launched a nationwide and decades-long Campaign for Energy Conservation since its “Eleventh Five-Year Plan” [State Council, 2007], which aimed to “reduce energy consumption per unit gross domestic product by 20%” from 2006 to 2010. However, although the whole society of China had made tremendous efforts, this goal wasn’t turned into reality in the end of 2010. As a result, in the latest “Twelfth Five-Year Plan” [State Council, 2012], the general goal of China’s Energy Conservation Campaign has to be adjusted to “reduce energy consumption per unit gross domestic product by 16%” from 2011 to 2015.

At the same time, Chinese policymakers and scholars began to reflect on the first five years of the Energy Conservation Campaign and tried to come up with effective strategies to win this critical campaign in the next a few decades. Many of them [CAE, 2009; Grimble and Wellard, 1997; Mushove and Vogel, 2005; Wu, Wu, and Lu, 2008; Yang and Zhu, 2008] have realized the necessity and importance to view China's Energy Conservation Campaign as a large complex sociotechnical system [Qian Xuesen, 1988; Dodder, Sussman, and McConnell, 2004]. Within such a system, it is crucial to identify the relevant stakeholders, understand their different roles and specific needs, prioritize the key relationships between stakeholders, and more importantly, manage these stakeholder relationships in order to ensure the "long-term success" [Freeman, 1984; Freeman, Harrison, and Wicks, 2007] of this campaign.

Clearly, initiated by the government, China's Energy Conservation Campaign sets quantitative requirements every five years for energy companies to improve their energy efficiency and reduce the level of energy consumption. In addition to the government and energy companies, however, there are many other stakeholders involved: Research and education organizations provide policy suggestions to the government; Financial institutions provide funds for energy companies to upgrade outdated equipment and adopt new technologies; Technology and consulting companies develop more energy-efficient equipment and technologies and then sell them to energy companies; Certification and inspection companies evaluate the efforts of energy-saving made by each energy company; Industrial associations issue industry standards for and collect statistical data about energy efficiency; Moreover, non-governmental organizations (NGO), public media, and even all the Chinese people, are also stakeholders participating in this nationwide and decades-long campaign.

With more stakeholders identified, it becomes more difficult to understand the networked and complicated relationships between stakeholders, as well as the impacts of these stakeholder relationships on the whole campaign, before stakeholders and their relationships can be effectively managed. This challenge brought the opportunity for us to apply the SVN analysis to China's Energy Conservation Campaign.

6.2.2 Research Collaboration, Data Collection, and Information Granularity

The SVN analysis for China's Energy Conservation Campaign was based on a two-year collaboration between MIT (System Architecture Group and Engineering Systems Division), Tsinghua University (Tsinghua-BP Clean Energy Research & Education Centre), and Chinese Academy of Engineering (China's Energy Development Strategy Project).

The input data for the SVN models were mainly collected over a three-month period in Beijing, China, during which more than twenty interviews were conducted with senior policy makers from the Chinese government, as well as representatives of Chinese energy companies, industrial associations, universities, and other major stakeholders. In addition to the interview data, hundreds of documents were reviewed prior to these interviews. Particularly, significant support in obtaining access to various stakeholders was provided by Dr. Bai Quan, Associate Director of the Energy Efficiency Center within the Energy Research Institute of NDRC (National Development and Reform Commission), and Professor Ni Weidou, Co-Chairman of the Energy Group of CCICED (China Council for International Cooperation on Environment and Development) and Chairman of the Science and Technology Committee of MOE (Ministry of Education).

Additional background for this case study can be found in Fu, Feng, Li, Crawley, and Ni [2011], and the details of the solicitation of modeling inputs, especially the answers to stakeholder questionnaires, have been discussed in previous chapters. However, it is important to highlight a different experience from the Project Phoenix case—because the temporal and spatial boundaries as well as the network contexts of the China case are much broader and deeper, as summarized at the beginning of this chapter, the granularity of modeling inputs collected from documents and stakeholder interviews are often not at the same level and even vary a lot—for example, some needs of Stakeholder A are directly provided by Stakeholder B, while Stakeholder A also has other needs fulfilled by subordinate organizations of Stakeholder B, which may not have interest in or control

over these value exchanges between its subordinate organizations and Stakeholder A. This situation poses challenges to choose the granularity level of the SVN models, and necessitates the consideration of organizational hierarchy, an intraorganizational phenomenon, in the SVN analysis. Based on the five principles of hierarchical modeling (see Section 5.3.4), a “top-down” approach is applied to the China case—the SVN model with a lower level of granularity will be built first, and then proceed to a higher level of granularity with the aid of the WSO and WVFO calculated from the previous level—therefore the focus of this chapter is put on the modeling results of each level SVN as well as the interactions between different levels of the SVN models. In addition, the concept of hierarchy will be discussed again in Appendix I when bridging the SVN analysis to the architecting process for large engineering projects.

6.3 Level One of China SVN Model

As discussed before, the SVN model for China’s Energy Conservation Campaign consists of three different levels: from Level One to Level Two and to Level Three, a “top-down” approach is applied step by step to decompose those large and important stakeholders on a higher level into a set of subordinate ones on a lower level. In other words, a lower-level model contains more details about the organizational hierarchies of large and important stakeholders, and therefore is often larger than a higher-level model in terms of the number of stakeholders and value flows. Note that in this dissertation the level of SVN model is different from the level of information granularity—a higher-level model has a lower level of information granularity, because fewer and larger stakeholders are included compared to a lower-level model—relatively speaking, a higher-level SVN model is more coarse-grained, while a lower-level SVN model is more fine-grained.

There are at least three reasons why a “top-down” approach is applied in hierarchical modeling of the SVN: First, the “top-down” approach is consistent with the nature order of human’s cognition, which always evolves from simple observations to complicated ones; Second, as a holistic network approach, starting from larger organizations and then

digging into their internal structures can ensure that the SVN analysis does not miss the big picture at the first place; Last but not least, the intraorganizational relationships are generally more dynamic than the interorganizational relationships [Simon, 1962, p. 477], and therefore should be more difficult to be captured in the SVN analysis, which is static by nature—to put it differently, the “top-down” approach guarantees that the merits of the SVN analysis are first applied to analyze those more static relationships in the higher-level SVN model.

Now this case study starts with the Level One of China SVN Model, and then proceeds to Level Two and Level Three step by step. For each step, the discussions are mainly focused on three aspects: (1) stakeholder maps of the qualitative SVN model and key results from the quantitative SVN model; (2) new insights gained for the previous higher-level SVN model; (3) implications for building the next lower-level SVN model.

6.3.1 Stakeholder Map and Key Results

Using the same color-coding system as previous chapters for market and nonmarket stakeholders as well as four different types of value flows, Figure 6-1 shows the stakeholder map for the Level One of China SVN Model, which consists of 10 stakeholders and 60 value flows.

As discussed in Section 6.1, the temporal and spatial boundaries as well as the network contexts of the China case are very broad, in light of the widespread influence of energy conservation on the Chinese economy and environment. Based on the previous case description, a number of large stakeholders are present in the Level One Model, such as the Chinese Government, Energy Companies, Chinese Industrial Associations, and so on. However, it should be noted that the purpose of this case study is not to map the whole Chinese society, but rather to gather the relevant inputs and outputs of the energy utilization system from a stakeholder perspective. More importantly, because this is the highest-level SVN model, the priority of network boundary specification should be put on identifying all the large stakeholders, instead of including too many subordinate ones

of a large stakeholder, in order to ensure that the SVN analysis does not miss the big picture at the first place. For example, from document review and stakeholder interviews, there are initially more than 30 governmental organizations or administrative institutions appearing in the long list of stakeholders, such as the National Energy Administration (NEA), Ministry of Environmental Protection (MEP), Environmental Protection and Resource Conservation Committee (EPRCC), and so on. Although many of them are closely related to the Energy Conservation Campaign, the Level One Model chooses to cluster them into one large stakeholder, that is, the Chinese Government. As discussed in Chapter 5, because in reality there are no unlimited computational and analytical resources, it is a reasonable and logical choice to allocate the limited resources on the organizational hierarchies of those most important stakeholders—if the results from the Level One Model don't recognize the Chinese Government as one of the most important stakeholders, it may not be necessary to consider the subordinate stakeholders within the Chinese Government at the beginning, which will consume more computational and analytical resources but produce less meaningful results.

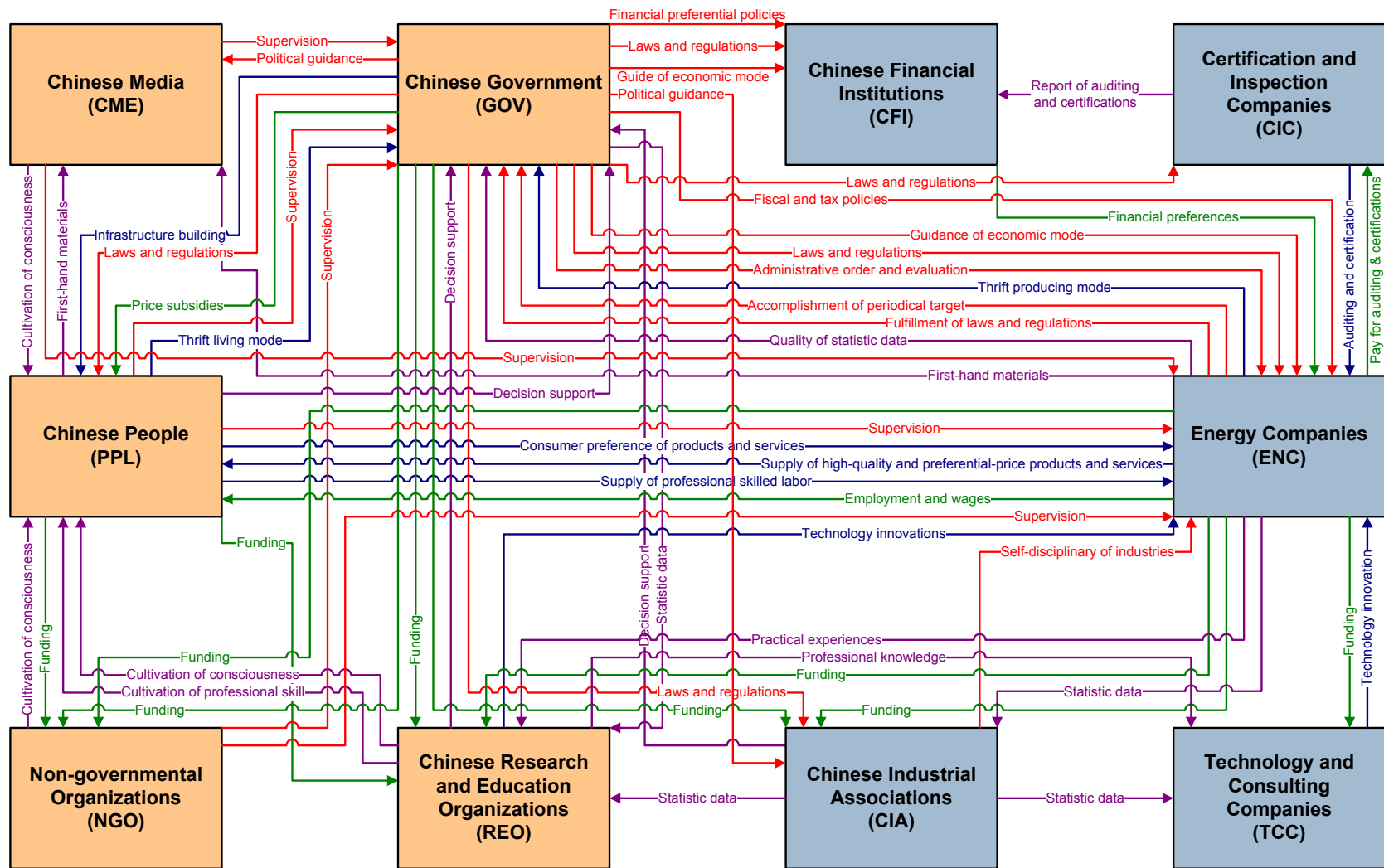


Figure 6-1: Stakeholder Map for Level One Model

Once the stakeholder map, or the qualitative SVN model, is obtained, as shown in the four-step modeling framework (see Figure 3-1), the following steps are quantifying value flows with stakeholder questionnaire, choosing the value propagation rule, searching for all the value cycles, and finally calculating the network statistics. Similar to the RuSakOil case in Chapter 3, “Need Intensity” and “Source Importance” are chosen as two attributes to describe value flows from both the demand side and the supply side of the recipient stakeholder (see Figure 3-9). In addition, according to the motivations discussed before, the primary question of interest for the China case is how to effectively manage the most important stakeholders through exploring their complicated organizational hierarchies, and meanwhile, we conclude in Chapter 5 that NWSO (Network Weighted Stakeholder Occurrence, a.k.a. Exchange Centrality II or Crawley Centrality II) is a more holistic measurement for stakeholder importance than WSO (Weighted Stakeholder Occurrence, a.k.a. Exchange Centrality I or Crawley Centrality I)—therefore the SVN analysis for China’s Energy Conservation Campaign should be not centered on a pre-chosen Focal Organization, but at the Whole Network level, by searching for all the value cycles in the SVN and then taking them as the sample space for network statistics. Correspondingly, “*abc*” is chosen as the value propagation rule in this case, and NWSO (see Equation 5-3) are the key statistics for the DSM modeling platform to calculate.

Figure 6-2 ranks the NWSO calculated from the Level One Model (see Figure 6-1). We observe that the two most important stakeholders surface as the Energy Companies (ENC) and the Chinese Government (GOV), while the least important stakeholder is the Certification and Inspection Companies (CIC). This observation identifies the ENC and GOV as the stakeholders that should be explored in more details, and the corresponding implications for the Level Two Model will be discussed later in this section. In addition, based on the previous discussion on decomposing the impacts of indirect stakeholder relationships (see Section 4.3.5.4), it is not difficult to find the reason why the CIC has a very low score of NWSO—those Certification and Inspection Companies are only tasked with the monitoring efforts for energy conservation and do not provide valuable outputs to most stakeholders—therefore the low score of NWSO is mainly the result of their poor structural position in the network.

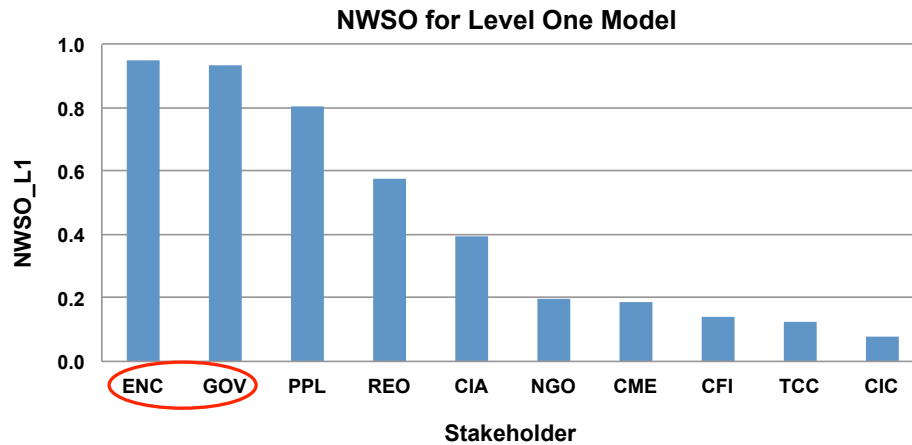


Figure 6-2: Network Weighted Stakeholder Occurrence (NWSO) for Level One Model

As discussed in Chapter 5, in addition to the NWSO, it is also necessary to examine the NWVFO (Network Weighted Value Flow Occurrence) in the network, because these most important value flows can help build the next level of the SVN model. Specifically, the top 20 (out of 60) value flows in the Level One Model (see Figure 6-1) are shown in Figure 6-3, and the total weights of these value flows already exceed 50% of the weights of all the value flows.

Figure 6-3 suggests that there is significantly less differentiation between these most important flows, as compared with the Project Phoenix case—the slope of the curve is much shallower.

In addition, two of the top four value flows represent flows provided to the Chinese People (PPL), rather than flows to the Energy Companies (ENC), which is not consistent with the fraction of energy consumed by the residential vs. industrial sectors—in China, the largest developing country in the world, industry is always the dominate sector for energy consumption and accounts for more than 60% of total primary energy consumption for decades [Zhou, McNeil, Fridley, et al., 2007, p. 10]—such an inconsistency indicates one of the limitations of the Level One Model.

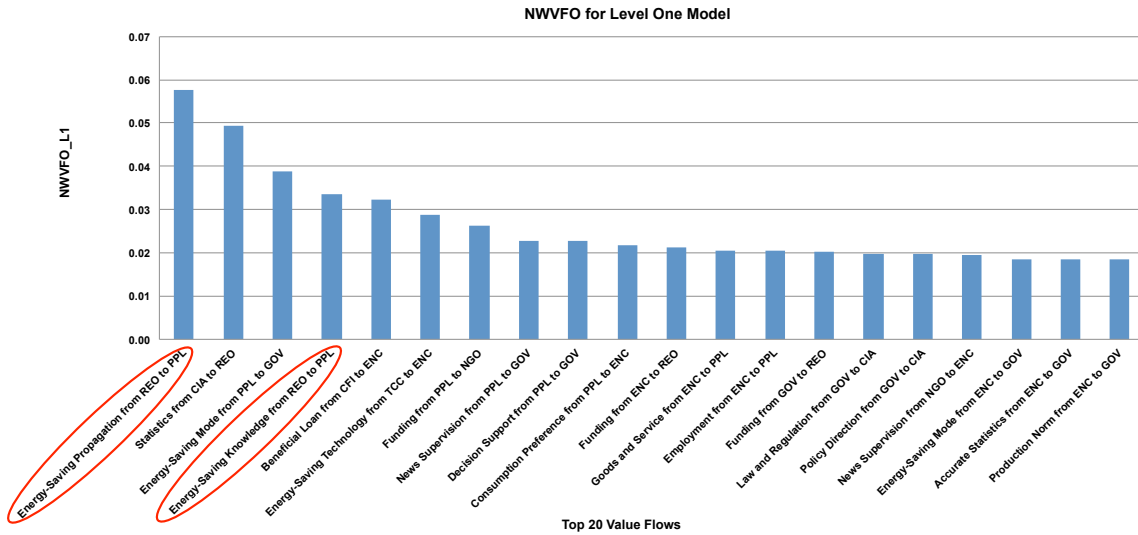


Figure 6-3: Network Weighted Value Flow Occurrence (NWVFO) for Level One Model

Moreover, from the level of detail captured in the Level One Model, we observe that the spatial and temporal breadth of the stakeholder network brings the difficulty of differentiating between different policies and strategies. Similarly, the aggregation of large institutional stakeholders makes it difficult to understand their power gained from exchange relationships and network structure, as their inputs and outputs are relatively generalized.

The above limitations motivate the examination of the Level Two Model, in which additional details of the two most important stakeholders (viz., ENC and GOV) are built out, and further, the impacts of stakeholder decomposition on value flows are also explored to reflect the greater level of detail for stakeholder relationships.

6.3.2 Major Steps from Level N to Level N+1

Before discussing the specific implications of the above results for the Level Two Model, this section summarizes the general process from the Level N Model to the Level N+1 Model into three major steps:

First, identify the stakeholders on Level N+1, based on the NWSO calculated from Level N. In the China case, the NWSO from the Level One Model indicates Energy Companies (ENC) and Chinese Government (GOV) are the two most important stakeholders (see Figure 6-2), and therefore they are decomposed into several subordinate stakeholders in the Level Two Model (see Table 6-1), so that more fine-grained decisions can be made by exploring the organizational hierarchies of these important stakeholders. Note that it is not necessary to decompose all the important stakeholders on the next level—for example, although Chinese People (PPL) is the third most important stakeholder (see Figure 6-2), compared to Energy Companies (ENC) and Chinese Government (GOV), Chinese People (PPL) has more homogeneous needs in the Energy Conservation Campaign and therefore can be treated as a whole group in the SVN—this is consistent with the criterion of “Necessity” in Principle B for hierarchical modeling discussed in Chapter 5. In addition, the number of stakeholders should always be kept manageable, because adding too many subordinate stakeholders at once into the next level may waste lots of computational resources and cause the SVN model not solvable. We suggest to categorize the granularity of information collected from documents and stakeholder interviews and also have a plan for the total number of organizational levels, before the hierarchical modeling actually begins.

Second, identify the value flows on Level N+1, based on both the NWSO and NWVFO calculated from Level N. Because the Level N+1 Model is only a “zoom-in” version of the Level N Model by decomposing large and important stakeholders into subordinate ones, it is obvious that the value flows should remain unchanged if their source and end stakeholders are the same as Level N. In other words, the evolution from Level N to Level N+1 will only impact the value flows that connect one or two decomposed stakeholders, and these value flows can be further classified into four groups: (1) value flows between the newly added “child” stakeholders and their “parent” stakeholder; (2) value flows between the “child” stakeholders themselves; (3) value flows between the “parent” stakeholder and other stakeholders; (4) value flows between the “child” stakeholders and other stakeholders. This classification can be better understood through a simplified example as below (see Figure 6-4):

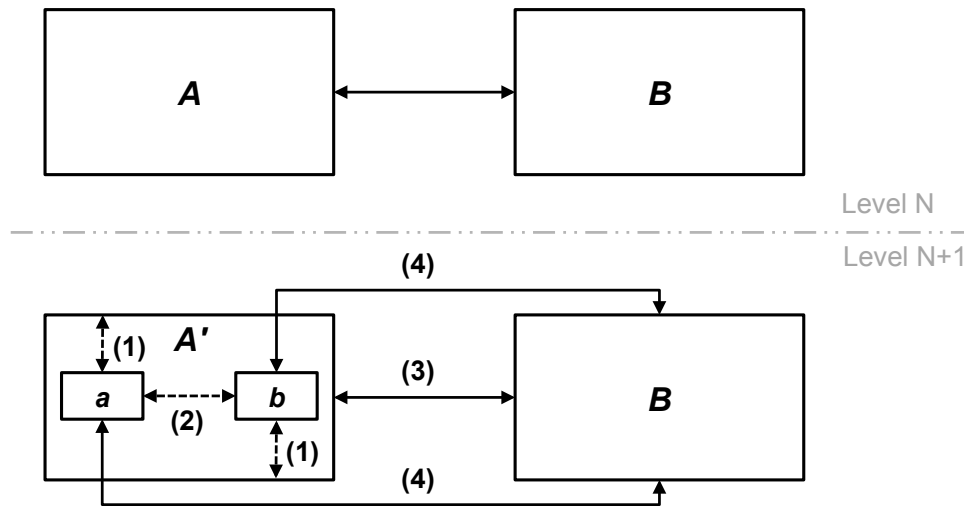


Figure 6-4: Impacts of Stakeholder Decomposition on Value Flow Identification

In the above figure, on Level N+1, “a” and “b” are the “child” stakeholders, and “A” is the “parent” stakeholder (viz., the remaining part of “A”), while “B” keeps the same as Level N. In addition, the above figure also labels four groups of value flows, which are impacted by stakeholder decomposition, correspondingly. Note that the first two groups of value flows describe the hierarchical relationships within a large and important stakeholder (viz., Stakeholder “A”) and have nothing to do with the existing value flows on Level N, and therefore both of them are represented by dotted arrows. By contrast, the last two groups of value flows are represented by solid arrows, because they are different from the first two groups in terms of their connections with the existing value flows on Level N. Arguably, when Stakeholder “A” is decomposed into “a”, “b”, and “A” on Level N+1, the existing value flows between “A” and “B” (see Figure 6-4) should also evolve into the value flows between “a” (and/or “b” and/or “A”) and “B”, depending on whether the existing value flows are substituted by a set of more detailed value flows, as well as who are the specific stakeholders responsible for those value flows. To put it differently, the third and fourth group of value flows belongs to interorganizational relationships and therefore should be closely related to the existing value flows on Level N, which are also interorganizational relationships; while the first and second group of value flows belongs to intraorganizational relationships and therefore cannot find the correspondents in the previous model.

Last but not least, once the stakeholders and value flows on Level N+1 are identified, the logical consistency between stakeholders and value flows as well as between these two levels should be carefully examined, before running the Level N+1 Model on the DSM modeling platform. We suggest preparing similar templates (see Figure 3-2 and Figure 4-2) for the newly added subordinate stakeholders, as well as to keep a good record for all the changes from Level N to Level N+1. Based on the modeling experience from other case studies, the increase of value flows is much faster than the increase of stakeholders, and therefore linear relationships are often not observed between two different levels.

6.3.3 Implications for Level Two Model

As discussed before, based on the NWSO calculated from the Level One Model (see Figure 6-2), Energy Companies (ENC) and Chinese Government (GOV) are chosen as two large and important stakeholders to be decomposed in the Level Two Model.

Generally speaking, Energy Companies (ENC) can be broken out into Energy Producing Companies (EPC) and Energy Using Companies (EUC), in terms of their different roles (supply vs. demand) in the energy market²⁰. In addition, with China's policy of reform and opening-up as well as the trend of globalization, more and more International Energy Companies (IEC) have shown their strong interest in providing financial and technology support for China's Energy Conservation Campaign.

Meanwhile, although Chinese Government (GOV) has a unique and very complicated structure including dozens of ministries, commissions, organizations, and institutions, the Chinese Energy Policymakers (ENP) and the Chinese Environmental Policymakers (ERP) are arguably two subordinate stakeholders most closely related to the Energy Conservation Campaign. Moreover, considering the vast territory of China as well as the huge imbalance of economic development between different areas, it is necessary to

²⁰ On a more fine-grained level, some energy transportation companies may be included as well.

differentiate the Chinese Local Governments (CLG) from the Chinese National Government (CNG) in light of their different stakes in the Campaign.

The above reasoning process is captured as the results of stakeholder decomposition (see Table 6-1). As emphasized before, the number of stakeholders has not seen a big increase (from 10 to 15), because adding too many subordinate stakeholders at once into the next level may waste lots of computational resources and cause the SVN model not solvable. In addition, at the beginning of this case study, it is designed to build a three-level SVN model for China’s Energy Conservation Campaign, and therefore the Level Two Model should only reflect the middle-level granularity of information collected from documents and stakeholder interviews.

Table 6-1: Stakeholder Decomposition from Level One Model to Level Two Model

CHINA SVN LEVEL ONE (10 stakeholders)	CHINA SVN LEVEL TWO (15 stakeholders)
Energy Companies (ENC)	Energy Using Companies (EUC)
	Energy Producing Companies (EPC)
	International Energy Companies (IEC)
Chinese Government (GOV)	Chinese National Government (CNG)
	Chinese Energy Policymakers (ENP)
	Chinese Environmental Policymakers (ERP)
	Chinese Local Governments (CLG)
Chinese People (PPL)	Chinese People (PPL)
Chinese Research and Education Organizations (REO)	Chinese Research and Education Organizations (REO)
Chinese Industry Associations (CIA)	Chinese Industry Associations (CIA)
Non-Governmental Organizations (NGO)	Non-Governmental Organizations (NGO)
Chinese Media (CME)	Chinese Media (CME)
Chinese Financial Institutions (CFI)	Chinese Financial Institutions (CFI)
Technology and Consulting Companies (TCC)	Technology and Consulting Companies (TCC)
Certification and Inspection Companies (CIC)	Certification and Inspection Companies (CIC)

6.4 Level Two of China SVN Model

6.4.1 Stakeholder Maps and Key Results

After determining the stakeholders, the value flows between the newly added seven stakeholders and other stakeholders as well as between seven stakeholders themselves can also be identified with the method introduced before (see Figure 6-4). The resulting stakeholder map for the Level Two Model is then visualized by different types of value flows (see Figures 6-5 ~ 6-9), which are too dense to show in one graphic. Specifically, two figures are needed to clearly display the Political Flows, and there are totally 176 flows connecting 15 stakeholders in the Level Two Model.

From these stakeholder maps, it can be immediately observed that the Energy Using Companies (EUC) are structurally more centered than the Energy Producing Companies (EPC) in the campaign, although their network statistics need to be further examined to see whether they receive lots of regulation from or provide valued outputs to other stakeholders. We also find that there does not exist a stakeholder taking centralized responsibility for energy policies and regulations, such as the Department of Energy in the United States, but rather a number of stakeholders combine to play this role, and they are labeled together as the Chinese Energy Policymakers (ENP).

Additionally, it can be observed that there are many value flows between the subordinate stakeholders (CNG, ENP, ERP, and CLG) decomposed from the Chinese Government (GOV), and these flows represent very complicated intraorganizational relationships. Through examining these relationships, it can be determined whether these stakeholders have distributed and independent responsibility, or whether there exists overlapping or potentially conflicting responsibility. In the case of the latter, the hierarchical modeling should be able to identify which stakeholders hold structurally strong positions, as well as formulate effective strategies to restructure the organizational hierarchies, so that these stakeholders' structural positions can be aligned with their given roles.

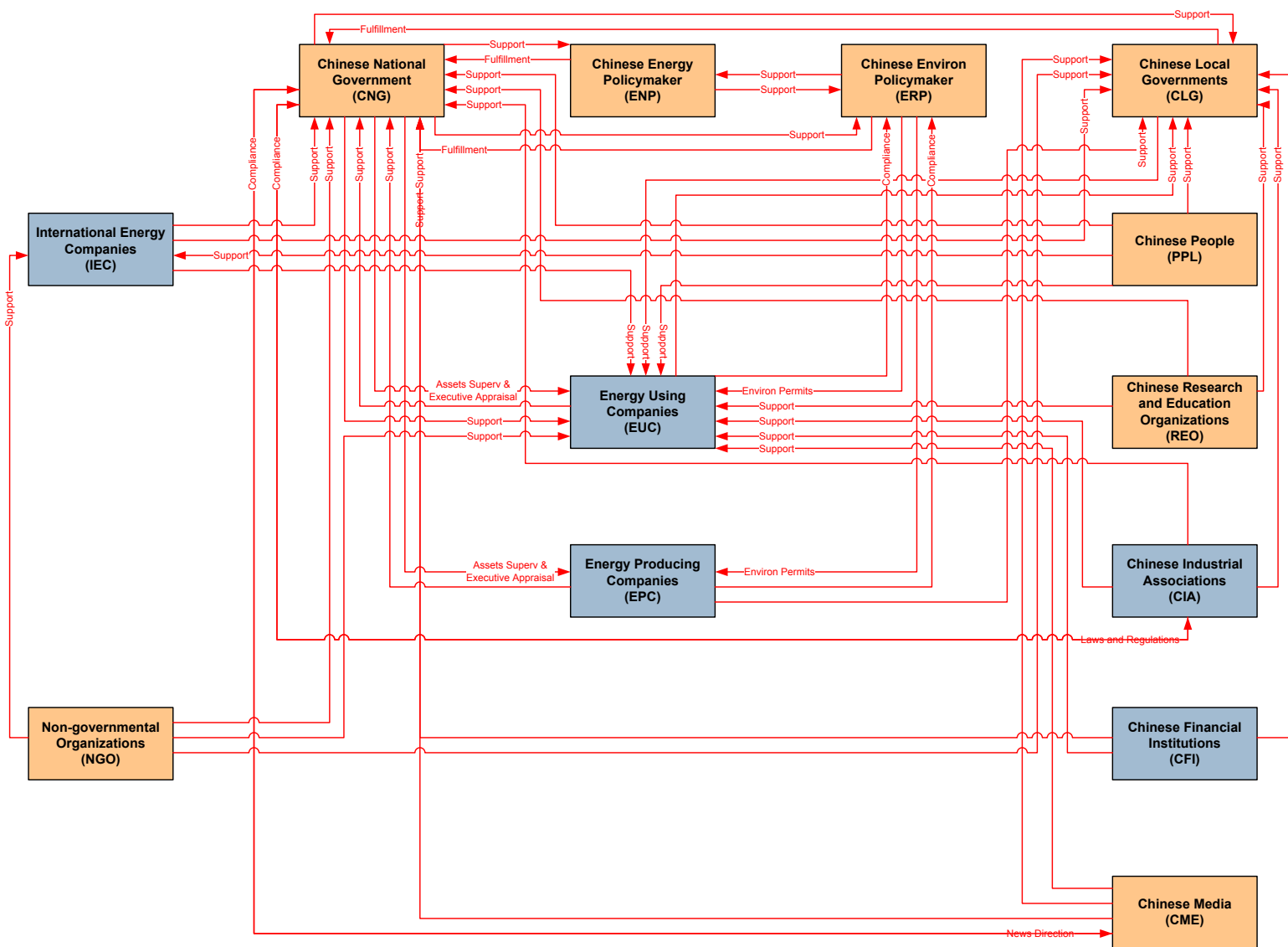


Figure 6-5: Stakeholder Map for Level Two Model (Political Flows Part 1)

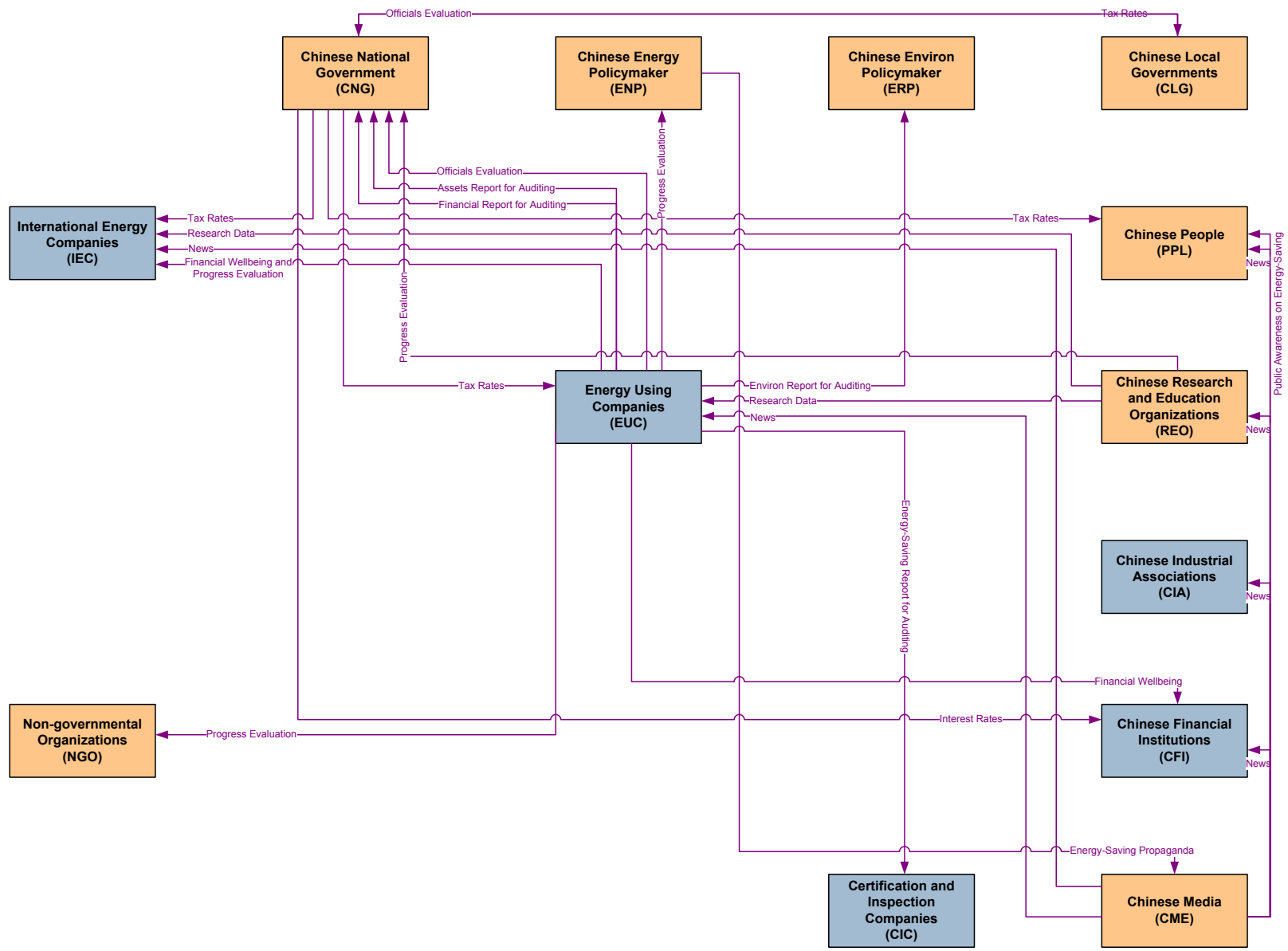


Figure 6-7: Stakeholder Map for Level Two Model (Information Flows)

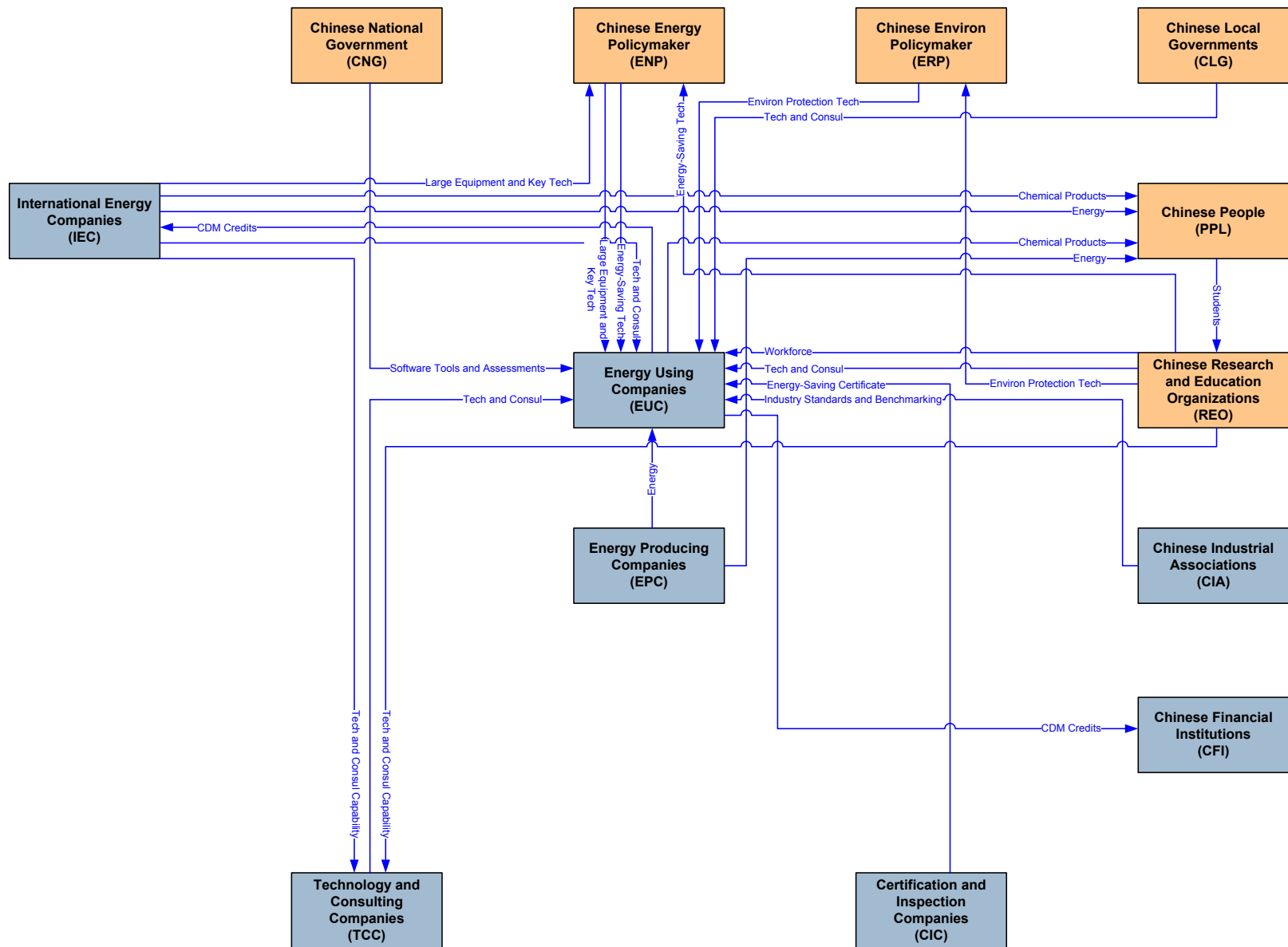


Figure 6-8: Stakeholder Map for Level Two Model (Goods/Service Flows)

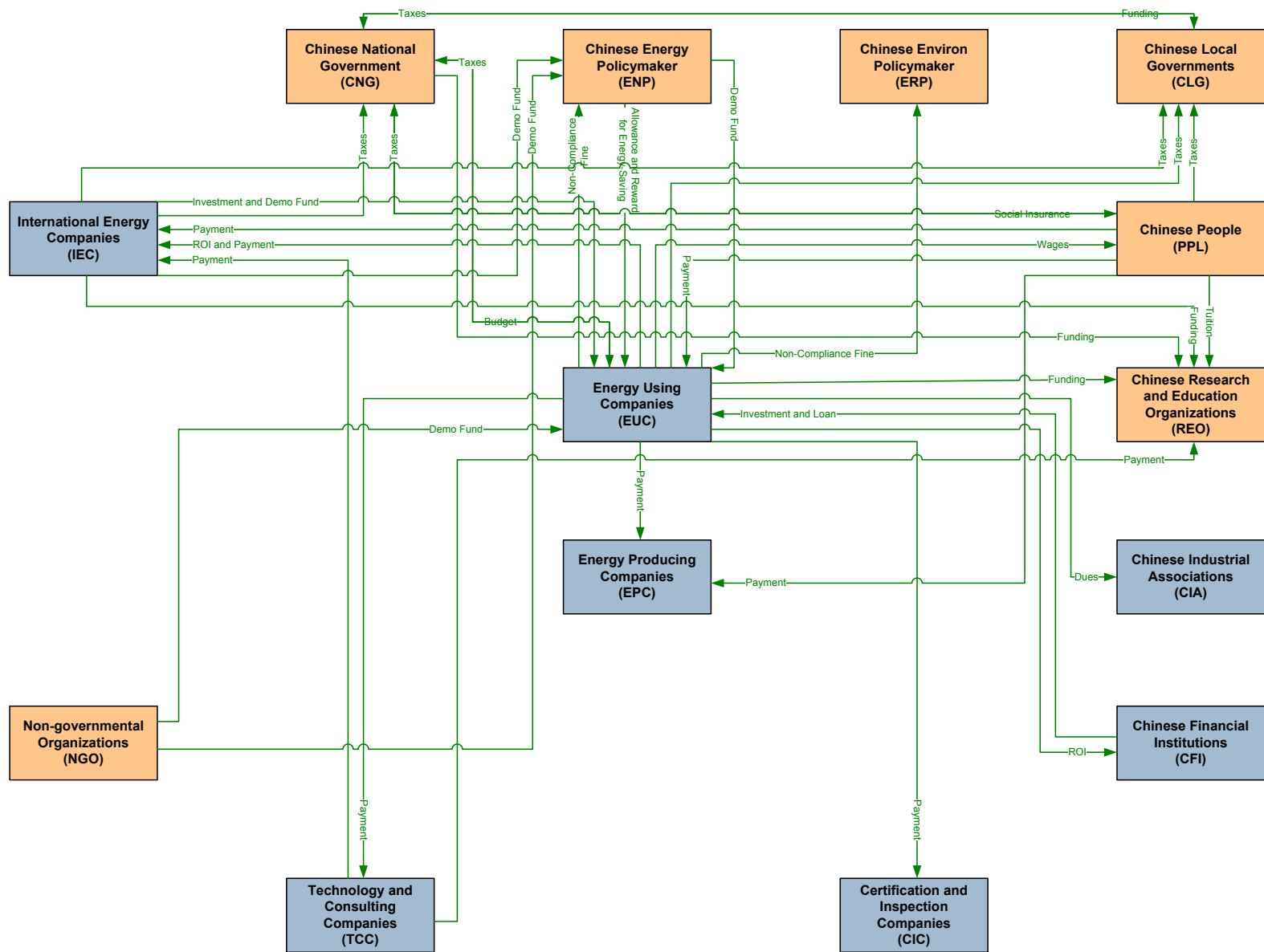


Figure 6-9: Stakeholder Map for Level Two Model (Financial Flows)

Similar to the Level One Model, the Network Weighted Stakeholder Occurrence (NWSO) and the Network Weighted Value Flow Occurrence (NWVFO) for the Level Two Model can be quickly calculated with the DSM modeling platform. The results are ranked in Figure 6-10 and Figure 6-11, respectively:

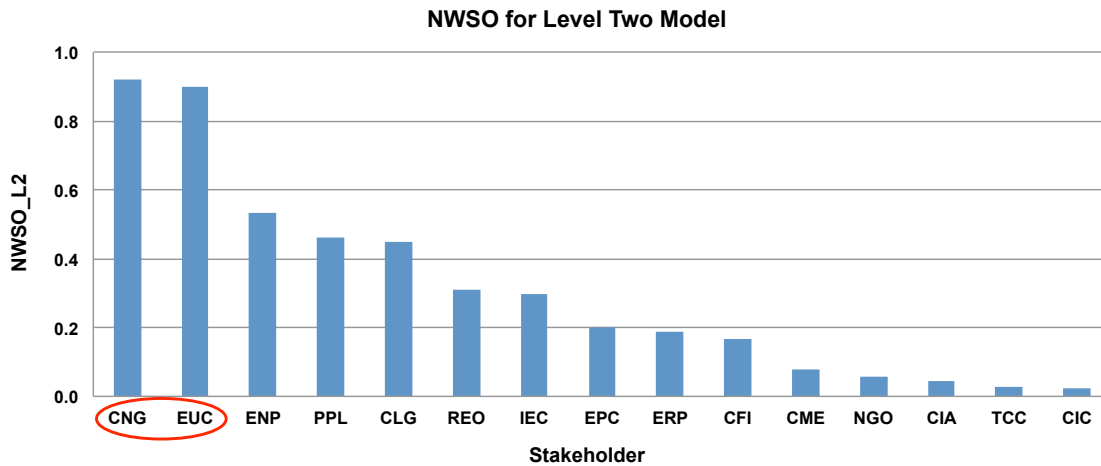


Figure 6-10: Network Weighted Stakeholder Occurrence (NWSO) for Level Two Model

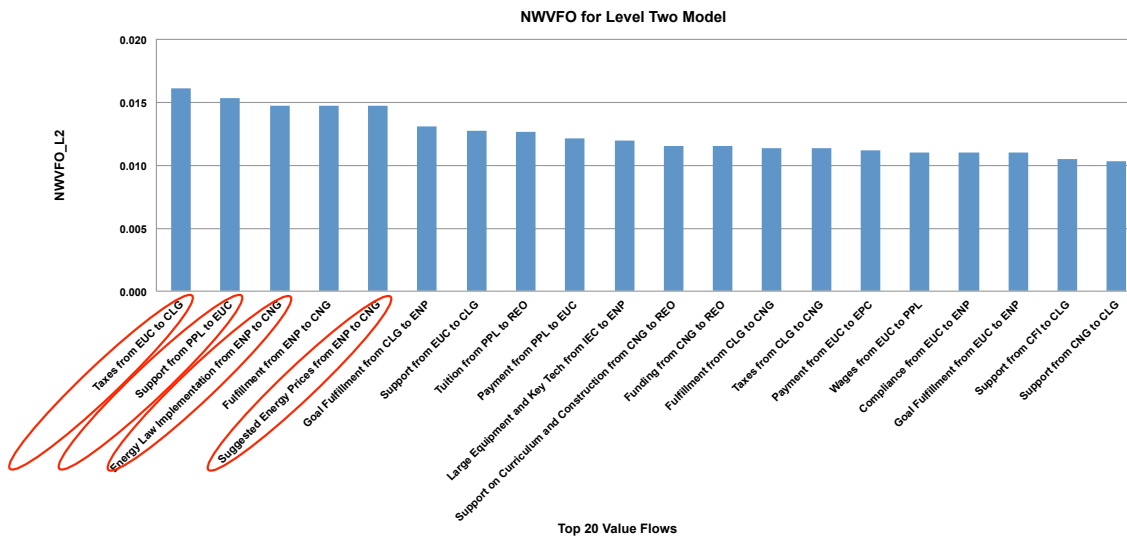


Figure 6-11: Network Weighted Value Flow Occurrence (NWVFO) for Level Two Model

Next, the above two figures will be compared to the corresponding results from the Level One Model. Based on such a comparison, a few new insights gained from the hierarchical modeling will be discussed in detail.

6.4.2 New Insights for Level One Model

Comparing Figure 6-10 with Figure 6-2, we observe that one child of each of the Chinese Government (GOV) and Energy Companies (ENC) is present as the two most important stakeholders on Level Two: Chinese National Government (CNG) and Energy Using Companies (EUC). However, the other children of the Chinese Government (GOV) are significantly less strong, most notably, the Energy Policymakers (ENP) and Environmental Policymakers (ERP), the two stakeholders chiefly responsible for the Energy Conservation Campaign. Given that the Energy Policymakers (ENP) and Environmental Policymakers (ERP) actually do not have sufficient power (from both exchange relationships and structural positions in the network) to regulate the stakeholders they are responsible for regulating, particularly the Energy Using Companies (EUC), we recommend that the Chinese National Government (CNG) should give the Energy Policymakers (ENP) and Environmental Policymakers (ERP) more power to regulate the energy consumptions and related environmental pollution of the Energy Using Companies (EUC)—in China, the majority of the Energy Using Companies (EUC) are state-owned enterprises, and their top executives are often senior government officers at the same time. Based on the previous observation for stakeholder maps, the first step may be taken is to integrate the distributed administrative authorities into a single governmental unit (for example, Ministry of Energy) to assume centralized responsibility for energy policies and regulations. More importantly, the performance of the top executives in the Energy Using Companies (EUC) should be linked to their achievements on energy conservation, which are directly evaluated by such an integrated governmental unit.

In addition, Figure 6-10 ranks the Energy Using Companies (EUC) much higher than the Energy Producing Companies (EPC), which is one of the least important stakeholders in the list. This result is not surprising and consistent with the previous observation on the structural advantages of the Energy Using Companies (EUC) in the stakeholder network. After carefully examining the inputs and outputs of these two stakeholders, we find that

the more central position of the Energy Using Companies (EUC) comes from the much heavier regulation on their energy consumption. This finding reflects a long-standing but controversial policy direction in China to only regulate the energy consumption of the Energy Using Companies (EUC) in the industry sector, mainly because of the concerns that the growth rate of China's economy would cause demand to always exceed supply in the energy market. The historic strategy of China has been to give relatively free reign to the Energy Producing Companies (EPC), to guarantee the capacity of energy supply can grow as quickly as possible.

Comparing Figure 6-11 with Figure 6-3, one of the most interesting findings is that in the Level Two Model, the top two value flows (viz., "Taxes from EUC to CLG", and "Support from PPL to EUC") surface the Energy Using Companies (EUC) as the key player in the Energy Conservation Campaign. This finding overcomes one limitation of the Level One Model (see Section 6.3.1), that is, the inconsistency between the importance of the residential and industrial sectors in the campaign (indicated by the NWVFO) and the actual fraction of energy consumed by these two sectors—based on statistical data [Zhou, McNeil, Fridley, et al., 2007, p. 10], the industrial sector in China accounts for more than 60% of total primary energy consumption for decades, while the residential sector only accounts for about 10% of total primary energy consumption—it is obvious that the industrial sector, or the Energy Using Companies (EUC) to be more specific, should be first addressed in the Energy Conservation Campaign to achieve more significant reductions of energy consumption.

Additionally, as discussed before, another limitation of the Level One Model is the difficulty of differentiating between different policies and strategies (see Figure 6-3), which is mainly caused by the spatial and temporal breadth of the stakeholder network in China's Energy Conservation Campaign. However, this situation is also improved by the greater level of detail captured in the Level Two Model. For example, two of the top five flows in Figure 6-11, that is, "Energy Law Implementation from ENP to CNG" and "Suggested Energy Prices from ENP to CNG", bring to attention two specific strategies (one is legislative and the other is economic) for the Chinese National Government

(CNG) to enhance the power of the Energy Policymakers (ENP) in the campaign, which is required by the previous comparison of the NWSO between Level One and Level Two. Another good example is the “Taxes from EUC to CLG”, which is the most important value flow in the Level Two Model. In fact, this flow highlights a tension between the Chinese Local Governments (CLG) and the Chinese National Government (CNG) regarding to their different stakes in the campaign—motivated by the direct economic benefits (and other indirect benefits such as the promotion of government officers because of their satisfactory performance in stimulating local economy), the Chinese Local Governments (CLG) often loosen their supervision on the energy consumption of the Energy Using Companies (EUC) and therefore sacrifice the achievement of the energy-saving goals set by the Chinese National Government (CNG).

6.4.3 Implications for Level Three Model

Similar to the Level One Model, the NWSO from the Level Two Model (see Figure 6-10) identify the Chinese National Governments (CNG) and the Energy Using Companies (EUC) as two stakeholders to be decomposed on Level Three. Table 6-2 takes the Chinese National Government (CNG) as an example to show the results of stakeholder decomposition. Further, using the method introduced before (see Figure 6-4), the value flows on Level Three can also be identified, and the resulting stakeholder map is visualized by different types of value flows (see Figures A-6-1 ~ A-6-6 in the Appendix).

However, based on the “Two Down, One Up” principle [Sutherland, 2009], the main purpose of the Level Three Model in this chapter is to examine the stakeholders and value flows on Level Two. Note that the Level Three Model is not computationally tractable (with the current modeling tool), but it is useful as a system check that the stakeholders illustrated on Level Two are an appropriate decomposition of the Level One Model.

Table 6-2: Stakeholder Decomposition from Level Two Model to Level Three Model (CNG only)

CHINA MODEL LEVEL 3-1 (5 Stakeholders)	CHINA MODEL LEVEL 3-2 (7 Stakeholders)	CHINA MODEL LEVEL 3-3 (22 Stakeholders)	CHINA MODEL LEVEL 3-4 (5 Stakeholders)
Communist Party of China	National Congress of CPC		
	Politburo		
	Central Organization Department		
	Central Commission of Discipline Inspection		
General Secretary / President			
Prime Minister	National Leading Group to Address Climate Change, Energy Conservation & Pollutant Discharge Reduction		
State Organs	National People's Congress	Environmental Protection and Resource Conservation Committee	
	State Council	National Development and Reform Commission	National Energy Administration
			Dept. of Resource Conservation & Environ. Protection
			Dept. of Industry
			Academy of Macroeconomic Research
		Ministry of Industry and Information Technology	Dept. of Energy Conservation & Integrated Utilization
		Ministry of Environmental Protection	
		Ministry of Science and Technology	
		Ministry of Education	
		Ministry of Finance	
		Ministry of Human Resources and Social Security	
		Ministry of Supervision	
		People's Bank of China	
		State-Owned Assets Supervision and Administration Commission	
		State Administration of Taxation	
		General Administration of Quality Supervision Inspection and Quarantine	
		National Bureau of Statistics	
		General Administration of Press and Publication	
		Xinhua News Agency	
		Chinese Academy of Sciences	
		Chinese Academy of Engineering	
		Development Research Center	
China Banking Regulatory Commission			
China Securities Regulatory Commission			
State Electricity Regulatory Commission			
Political Consultative Conference			

6.5 Policy and Strategy Recommendations

Based on the hierarchical modeling for the SVN of China's Energy Conservation Campaign, a few policy and strategy recommendations are summarized as below:

- **Placing** the priority of the campaign on reducing energy consumption of the industrial sector and improving the efficiency of energy utilization;
- **Managing** the energy consumption on the supply side and coordinating the development of economy with energy production on the national level;
- **Integrating** the distributed administrative authorities into one single government organization, such as the Ministry of Energy, to assume centralized responsibility for energy policies and regulations;
- **Enhancing** the power of energy and environmental policymakers, through administrative (evaluating the performance of top executives in state-owned enterprises), legislative (implementing energy law), economic (adjusting energy prices), and other means;
- **Balancing** the different interests of national government and local governments, such as designing a tax structure more favored by local governments, or linking the overall performance of local government officers with their achievements in the campaign.

As introduced before, the stakeholder analysis for China's Energy Conservation Campaign is still in its early stage, and most existing research [Wu, Wu, and Lu, 2008; Yang and Zhu, 2008] only focuses on stakeholder identification and categorization. Through the case study in this chapter, the SVN analysis not only provides a rigorous framework for better understanding the networked relationships between stakeholders, but also proposes a systematic way to manage the complexity of stakeholder networks.

6.6 Chapter Summary

In this chapter, the Whole Network analysis and the DSM modeling platform developed in Chapter 5 are applied to conduct the SVN analysis for China's Energy Conservation Campaign, which has much broader spatial and temporal boundaries as well as more complicated network contexts than the previous Project Phoenix case.

Through this prospective case study, the instrumental power of the SVN analysis for better managing the complexity associated with stakeholder networks is demonstrated. Specifically, following the five principles for hierarchical modeling, this chapter models the SVN of China's Energy Conservation Campaign from top to down into three different levels: On one hand, the NWSO and NWVFO calculated in a higher-level model identify the most important stakeholders and value flows to be decomposed in a lower-level model; On the other hand, the NWSO and NWVFO calculated in a lower-level model provide more fine-grained decision support for the precedent higher-level model.

Putting Chapters 5 and 6 together, the second module of the main body of this dissertation is now completed (see Figure 1-1), and one should be ready to conduct the SVN analysis for more complicated cases, from the perspective of the whole network. Next, set against an even broader backdrop, the possible ways to apply the SVN analysis to design the physical architectures of large engineering projects are further explored in Appendix I.

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CHAPTER 7. CONCLUSIONS AND FUTURE WORK

“LEPs (Large Engineering Projects) are important not only because they transform the physical landscape and change the quality of human life, but because they are the crucibles in which new forms of collaboration are developed. The study of LEPs provides insights into the workings of human organizations, both large and small.”

— Miller and Lessard [2001, p. 1]

7.1 Dissertation Summary

In order to better meet the challenges arising from as well as embrace the opportunities brought by the exogenous and endogenous changes that large engineering projects are experiencing today, we advance a multi-disciplinary approach, namely, the Stakeholder Value Network (SVN) analysis, as a unique lens to examine, understand, model, and manage the multi-type and networked relationships between the large engineering projects and their various stakeholders. Meanwhile, as the “real-life social experiments” [Miller and Lessard, 2001, p. 10], the study of today’s large engineering projects itself provides insights into the workings of human organizations in a highly interwoven and rapidly changing socio-technical system; and “seeing the big through the small” [Stolte, Fine, and Cook, 2001, p. 387], these insights can further promote new developments across engineering, management, and social sciences.

First of all, based on Social Exchange Theory (SET), or the “economic analysis of noneconomic social situations” [Emerson, 1976, p. 336], the SVN approach unifies both social and economic relationships into a common framework, under which all the stakeholder relationships are formed by the use of subjective utility analysis (from the Rational Choice Theory) and the comparison of alternatives (from the Behaviorist

Psychology). Further, restricted and generalized exchanges are taken as two basic patterns for stakeholders to exchange both tangible and nontangible value, and meanwhile, the missing link between the relationship types and the exchange patterns is also identified. In the end, strategic implications, such as the stakeholder importance (a.k.a., salience, power, etc.), are inferred as the confluence between value exchanges and the structural properties of the network consisting of stakeholders and their exchange relationships.

According to the above theoretically grounded assumptions, a four-step methodological framework (viz., mapping, quantifying, searching, and analyzing) is developed for the SVN analysis. Along this development, a rigorous network utility model is built to quantify the value delivered to the focal organization (viz., large engineering projects) through the channel of generalized exchanges. In addition, the benefits from as well as a feasible way for the integration between stakeholders and strategic issues are also explored. Moreover, in order to reduce the egocentric bias associated with the perspective of a pre-selected focal organization, the above four-step framework is further developed to interpret the implications of the SVN from the perspective of the whole network. The computational challenges arising from this new development are also met by the construction of a dedicated mathematic tool for the SVN analysis, namely, the DSM (Dependency Structure Matrix) modeling platform.

Corresponding to the two-stage development of the methodological framework, two large real-world engineering projects are chosen as cases to apply the SVN analysis from the focal organization perspective and the whole network perspective, respectively. The first one, Project Phoenix, is a retrospective case—based on this case study, the strength of the SVN analysis in terms of capturing the impacts of indirect stakeholder relationships is validated, through a comparison of important stakeholders between Mangers' Mental Model, the "Hub-and-Spoke" Model, and the SVN Model. The second one, China's Energy Conservation Campaign, is a prospective case—in this case study, five basic principles are proposed for modeling the intraorganizational hierarchies of large and important stakeholders, and then these principles are tested as an effective means to

manage the “structural complexity” [Moses, 2004a, p. 9] of the SVN in the modeling process.

The SVN approach is now complete with the above theory, methodology, tool, and meaningful findings from two different case studies. At the end of this dissertation, two conceptual innovations, namely, Stakeholder-Oriented Architecting Process and Value Exchange Rates & Matrix, are also presented to bridge the gap between the SVN analysis and the architecting process for large engineering projects as well as engineering systems in general.

7.2 Contributions and Implications

7.2.1 Theoretical, Methodological, and Empirical Contributions

The academic contributions of this dissertation can be synopsized from three aspects:

Theoretical Contributions

In this dissertation we have:

- **Enhanced** the economic perspective of modern Strategic Management by grounding the SVN approach in Social Exchange Theory (SET) and unifying both social and economic relationships into a common framework for analysis;
- **Advanced** the Network Theory of Stakeholder Influences by not only moving beyond dyadic ties, but also considering the simultaneous interactions between multiple types of stakeholder relationships;
- **Improved** the descriptive accuracy of the Stakeholder Salience Theory by interpreting stakeholder importance or power as a secondary and derivative phenomena determined by both exchange relationships and network structures;
- **Integrated** Stakeholder Theory with Strategic Issue Management through transforming the SVN into multiple Issue Networks, which can provide greater normative power for stakeholder balance with a simpler analysis.

Methodological Contributions

We also have:

- **Closed** the gap for the Network Analysis in Social Sciences by constructing an effective modeling tool and defining useful network measurements for a rigorous analysis of the multi-type and indirect interorganizational relationships;
- **Developed** the Whole Network analysis for the SVN to reduce the egocentric bias associated with the pre-selected focal organization as well as to study the networks without a clear central actor;
- **Provided** a transparent, collaborative, and alive platform for different teams in a large engineering project as well as for different stakeholders to share important knowledge that is otherwise difficult to express or communicate.

Empirical Contributions

Finally, we have:

- **Conducted** one of the very first empirical studies in business and management for understanding the important role of generalized exchanges in value creation and trade among stakeholders in a network;
- **Discovered** the evidence for the similarity between Managers' Mental Model and the "Hub-and-Spoke" Model, as well as for the substantial impacts of indirect relationships captured in the SVN model;
- **Demonstrated** the feasibility of using hierarchical models to manage the structural complexity of the SVN, and also the possibility of obtaining additional insights from different levels of the network model.

7.2.2 Managerial Implications and Policy Recommendations

More specifically, the implications and recommendations derived from two case studies in this dissertation are also recapitalized as below:

Managerial Implications for Large Engineering Projects Based on Project Phoenix

- **Impacts of Indirect Stakeholder Relationships:**
 - The typical Managers' Mental Model is very similar to the "Hub-and-Spoke" Model, and both of them are likely to miss key stakeholders, such as the Public Media and the Local Government in Project Phoenix;
 - The SVN Model identifies the important omitted stakeholders, such as the Public Media and the Local Government in Project Phoenix, even with only prior information, by considering the impacts of indirect stakeholder relationships or generalized exchanges, which prevail over direct stakeholder relationships or restricted exchanges under the condition that social exchanges become the dominant phenomena in the stakeholder network;
 - The impacts of indirect stakeholder relationships or generalized exchanges can be further decomposed into the "exchange" and "structural" parts, based on the assumption that stakeholder power is the outcome of both exchange relations and network positions. Correspondingly, different strategies can be formulated to gain more influence on other stakeholders, through an "exchange" (decrease or increase the value delivered through relationships), "structural" (sever existing relationships or build new relationships), or mixed way.
- **Importance of Issue Networks:**
 - Issue Networks arrive at the same conclusions as the SVN Model, with much simpler analysis;
 - Issue Networks provide greatest normative power since they identify those stakeholders that place large values (positive and negative) on the two opposing types of issues (taxes and jobs vs. pollutions) and thus can link them internally, as well as those stakeholders that are "closest" to each other to effect this "issue trade". The central issue for Project Phoenix is that it has negative balance on pollutions and positive balance on taxes as well as jobs, but that in general these apply to different stakeholders;

- Under such a circumstance, generalized exchanges, which include more than two parties in value exchange, can certainly shed light on formulating “indirect” strategies to influence the stakeholders with positive balance and those with negative balance at the same time.

Policy Implications for National Programs Based on China’s Energy Conservation Campaign

- **Five Principles for Hierarchical Modeling:**

- Principle A: In the SVN, hierarchy is not an interorganizational, but an intraorganizational phenomenon;
- Principle B: In the SVN, hierarchical modeling is not a bottom-up, but a top-down approach to decomposing a stakeholder into a set of subordinate ones;
- Principle C: In the SVN, importance and necessity are two criteria to identify the stakeholders to be decomposed on the next level of hierarchical model;
- Principle D: In the SVN, Network Weighted Stakeholder Occurrence (NWSO) is a more holistic measurement for stakeholder importance and therefore should be applied in hierarchical modeling;
- Principle E: In the SVN, Network Weighted Value Flow Occurrence (NWVFO) is a more holistic measurement for value flow importance and can help NWSO build the hierarchical model on the next level.

- **Five Recommendations for Energy-Conservation Campaign:**

- Placing the priority of the campaign on reducing energy consumption of the industrial sector and improving the efficiencies of energy utilization;
- Managing the energy consumption on the supply side and coordinating the development of economy with energy production on the national level;
- Integrating the distributed administrative authorities into one single government organization, such as the Ministry of Energy, to assume centralized responsibility for energy policies and regulations;

- Enhancing the power of energy and environmental policymakers, through administrative (evaluating the performance of top executives in state-owned enterprises), legislative (implementing energy law), economic (adjusting energy prices), and other means;
- Balancing the different interests of national government and local governments, such as designing a tax structure more favored by local governments, or linking the overall performance of local government officers with their achievements in the campaign.

7.3 Limitations and Future Work

7.3.1 Short List of Limitations

In this dissertation, along the comprehensive treatise on the multi-type and networked relationships between large engineering projects and their stakeholders, a short list of limitations still remain:

- **Normative Justification:** The SVN approach is mainly developed for the objective of descriptive accuracy and instrumental strength, and therefore lacks a thorough consideration of normative justification;
- **Bounded Rationality:** The SVN approach heavily relied on the rational choice model borrowed by the Social Exchange Theory (SET) from neoclassical economics, and therefore can be improved with the latest development in behavioral and complexity economics;
- **Strategy Implementation:** The SVN approach does not provide practical guidelines to effectively implement the stakeholder strategies derived from generalized exchanges, which often bring the problem of social dilemma such as moral hazard and free-riding, and therefore these guidelines are much desired in the real world to promote the trust between different stakeholders;

- **Homogeneous Utility:** The SVN approach utilizes the Multi-Attribute Utility Theory (MAUT) as the mathematical tool to quantify the value flows by the subjective utilities of the recipient stakeholders, but for simplification, the same utility function has been applied for all the stakeholders, and moreover, such a utility function has not been calibrated with the data from psychological experiments;
- **Meso-Level Networks:** The SVN approach often deals with the models for interorganizational networks on the “meso-level” of human society, and the linkage between the SVN models and other networks on the individual, micro-, or macro- levels has not been fully understood;
- **Information Bias:** A beauty of the SVN approach comes from the convenience that once the network model is built, each stakeholder can be taken as the focal organization to conduct various analyses, but before that, a “default” focal organization has always been chosen to help specifying the network boundaries and/or satisfying the research sponsors, and therefore it is very difficult to avoid the bias from the pre-selected focal organization when collecting information for model construction at the beginning of the SVN analysis;
- **Static Characteristics:** Last but not least, the SVN approach is inherently static and more like a “snapshot” for the value exchanges among stakeholders at a specific temporal stage, and therefore is unable to illustrate the longitudinal evolution of the stakeholder network.

7.3.2 Future Work: Theoretical, Methodological, and Empirical Directions

Although the above is by no means a complete list, one should have not been intimidated by the limitations—as wisely commented by Box and Draper [1987, p. 424], “Essentially, all models are wrong, but some are useful.” and “Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful.” [Box and Draper, 1987, p. 74]—articulating these limitations will actually help with the appropriate application of the SVN approach. More importantly, except the inherent limitations of information bias and static characteristics, other limitations in the above list also mark a

promising path for future work on theoretical construction, methodological development, and empirical study:

Theoretical Construction

- **With Stakeholder Theory:** Justify the normative validity of the SVN approach by studying the “problem of the ethics of capitalism”, or “putting together thinking about questions of ethics, responsibility, and sustainability with the usual economic view of capitalism” [Freeman, Harrison, Wicks, et al., 2010, pp. 4-5 and p. 29];
- **With Social Exchange Theory:** Improve the rational choice model borrowed from neoclassical economics by introducing the latest development in behavioral and complexity economics, such as bounded rationality [Simon, 1972, 1997], intertemporal choice [Loewenstein and Prelec, 1992; Berns, Laibson, and Loewenstein, 2007]; prospect theory [Kahneman and Tversky, 1979; Tversky and Kahneman, 1992], evolutionary game theory [Weibull, 1997], and out-of-equilibrium dynamics [Arthur, Durlauf, and Lane, 1997] among others;
- **With Institutional Theory:** Enrich the substance of the SVN approach by introducing institutions, which are the “humanly devised constraints that structure political, economic and social interaction” [North, 1991, p. 97], possibly as the “game rules” governing the value exchanges of stakeholders, because “institutional theory attends to the deeper and more resilient aspects of social structure” [Scott, 2005, p. 460];
- **With Innovation and Entrepreneurship:** Identify the fundamental sources of value creation for stakeholders by combining the SVN approach with the theory of innovation systems—both Marx [1906] and Schumpeter [1934, 1942] saw technology and technical change “as a central factor underlying organization and political dynamics and as a critical determinant of group power and individual outcomes” [Tushman and Nelson, 1990, p. 1].

Methodological Development

- **On Managerial Mindset:** Search for “what to teach managers and students about what it takes to be successful in the current business world” [Freeman, Harrison, Wicks, et al., 2010, pp. 4-5 and p. 29] by synthesizing the lessons learned from the SVN research, such as the importance of indirect stakeholder relationships on the long-term success of large engineering systems;
- **On Social Dilemma:** Understand how to implement generalized exchanges as effective strategies in the business world and avoid the potential moral hazard and free-riding problems by taking advantage of the network game theory [Myerson, 1977; Jackson, 2008], the stag hunter games [Skyrms, 2004], among other useful methods, regarding to different motivations behind generalized exchanges which “span the gamut from pure altruistic (Sahlins, 1972) to norm-based behavior (Ekeh, 1974) to behavior that is based on rational choice and instrumental incentives (Olson, 1965)” [Levine and Shah, 2003, pp. 3-4];
- **On System Architectures:** Bridge the gap between the SVN analysis and the architecting process for large engineering projects by further developing the Stakeholder-Oriented Architecting Process and Value Exchange Rates & Matrix conceived in Appendix I.

Empirical Study

- **For Generalized Exchanges:** Interpret the important role of generalized exchanges, which provides “a partial answer to the question of why the whole of stakeholder relationships can be greater than the sum of its parts” [Wicks and Harrison, 2013, pp. 105-106], in value creation and trade among stakeholders by conducting a significant amount of case studies, in addition to the Project Phoenix and China’s Energy Conservation Campaign discussed in this dissertation;
- **For Stakeholder Utility:** Calibrate the utility functions of different stakeholders and the “maximum distance” [Harary, Norman, and Cartwright, 1965; Jackson, 2008] to trace the received value with their bounded rationality by collecting and analyzing empirical data from well-designed interviews and psychological experiments;

- **For Other Networks:** Test the generalizability of the SVN approach by exploring the similarities as well as differences between the meso-level (interorganizational) networks discussed in this dissertation and other individual, micro- (intraorganizational), and macro-level (across industry sectors) networks.

Now the journey of this dissertation comes to an end, however, it is just the beginning of a splendid march for better understanding and managing today's large engineering projects as well as advancing engineering systems into a new discipline.

Dream. Explore. Discover.

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DISSERTATION PUBLICATIONS

I. Referred Journal Articles

- Cameron, B. G., E. F. Crawley, W. Feng, and M. Lin. [2011]. "Strategic Decisions in Complex Stakeholder Environments: A Theory of Generalized Exchange." *Engineering Management Journal* **23**(3): 37-45.
- Fu, F., W. Feng, Z. Li, E. F. Crawley, and W. Ni. [2011]. "A Network-based Modeling Framework for Stakeholder Analysis of China's Energy Conservation Campaign." *Energy* **36**(8): 4996-5003.

II. Conference Papers

- Feng, W., E. F. Crawley, O. L. de Weck, R. Keller, and B. Robinson. [2010]. "Dependency Structure Matrix Modelling for Stakeholder Value Networks." *Proceedings of the 12th International Dependency and Structure Modelling Conference*. July 22-23, 2010. Cambridge, UK: 3-16.
- Feng, W., E. F. Crawley, O. L. de Weck, D. R. Lessard, and B. G. Cameron. [2012]. "Understanding the Impacts of Indirect Stakeholder Relationships: Stakeholder Value Network Analysis and Its Application to Large Engineering Projects." *The Strategic Management Society (SMS) 32nd Annual International Conference*. October 6-9, 2012. Prague, Czech Republic.
- *Nominees, the SMS Best Conference Paper Prize (top 51 out of 1200) and the SMS Best Conference Paper Prize for Practice Implications (top 31 out of 1200).*
 - *Also published as working papers ESD-WP-2012-26 and SSRN-id2162037.*
- Feng, W., D. R. Lessard, E. F. Crawley, O. L. de Weck. [2013]. "Stakeholder Value Network and Strategic Issues for the Shaping of Large Engineering Projects." *Engineering Project Organizations Conference (EPOC) – International Community*. July 9-11, 2013. Winter Park, CO.
- Feng, W., E. F. Crawley, D. R. Lessard, B. G. Cameron, and O. L. de Weck. [2013]. "Moving beyond Single Relations: A Multi-Relational Network Theory of Stakeholder Power." *The Strategic Management Society (SMS) 33rd Annual International Conference*. September 28 ~ October 1, 2013. Atlanta, GA.

III. Book Chapters

- Feng, W., E. F. Crawley, O. L. de Weck, R. Keller, B. Robinson, and J. Lin. [2012]. "BP Stakeholder Value Network." in *Design Structure Matrix Methods and Applications* by Eppinger, S. D. and T. R. Browning. Cambridge, MA: MIT Press: 122-127.

In Preparation

- Feng, W., E. F. Crawley, D. R. Lessard, O. L. de Weck, and B. G. Cameron. [2013]. “Stakeholder Value Network: An Integrated Multi-Relational Approach for Stakeholder Salience and Strategic Issues.” Manuscript aiming for submission to *Academy of Management Review*.
- Feng, W., E. F. Crawley, D. R. Lessard, O. L. de Weck, and B. G. Cameron. [2013]. “Understanding the Impacts of Indirect Stakeholder Relationships: Stakeholder Value Network Analysis and Its Application to Large Engineering Projects.” Manuscript aiming for submission to *Strategic Management Journal*.
- Feng, W., E. F. Crawley, D. R. Lessard, O. L. de Weck, and B. G. Cameron. [2013]. “A Multi-Relational Network Approach Based on Generalized Exchanges: Theory, Methodology, Tool, and Evidence.” Manuscript aiming for submission to *Social Networks*.
- Feng, W., E. F. Crawley, F. Fu, Z. Li, and W. Ni. [2013]. “Stakeholder Value Network Analysis for China’s Energy Conservation Campaign (Part II): Hierarchical Modeling and New Findings.” Manuscript aiming for submission to *Energy*.

APPENDIX I: FROM SVN TO SYSTEMS ARCHITECTING

“Changes in the world’s political, economic and technological realms in the past century have placed great stresses on approaches to management and system design. The changes that have had the greatest impact are the increase in size and complexity of the human organizations and technical systems needed in the world today, and the rate of change in the external environment with which these organizations and systems must cope.”

— Joel Moses (from [Hughes, 1998, p. 1])

A.1 Introduction

From Chapter 2 to Chapter 6, the theory, methodology, and tool for the SVN analysis are developed step by step, with the application to two cases of large engineering projects. On the basis of these chapters and against an even broader backdrop, this Appendix briefly explores the possible ways to bridge the SVN analysis to Systems Architecting, which is defined as “the process by which standards, rules, system structures and interfaces are created in order to achieve the requirements of a system” [ESD Symposium Committee, 2006, p. 6], so that the synergy between stakeholder management and system design can be achieved to ensure the long-term success of large engineering projects in a complex and dynamic socio-technical environment.

Specifically, based on the unique features of the SVN analysis, which models the multi-type and networked stakeholder relationships as value exchanges, two promising methods are conceived in this Appendix, namely, the **Stakeholder-Oriented Architecting Process** and the **Value Exchange Rates and Matrix**.

A.2 Stakeholder-Oriented Architecting Process

Figure A-1-1 illustrates the conceptual framework of the Stakeholder-Oriented Architecting Process, which consists of two major parts, that is, the Stakeholder Networks on the left and the Large Engineering Projects on the right.

Borrowing the symbols from the Object-Process Methodology (OPM) [Dori, 2002], the architecting process for Large Engineering Projects can be further divided into four columns, from left to right: Intent, Function (Process and Operand), Form (Object), and the Projects, which represent the standard steps for engineers to design the physical architectures of Large Engineering Projects. Specifically, the first step is usually transforming the intent to a few solution-neutral designs, and then defining the specific function of the selected design, and finally choosing the specific forms and integrating them into a complete artifact. Note that from the perspective of Engineering Systems, complexity and uncertainty are two basic characteristics associated with the architectures of Large Engineering Projects, and today's engineers should not only care about the immediate value of the architectures, such as cost and schedule, but also take their life-cycle value into consideration. Using the terminology of Engineering Systems, life-cycle value is reflected through many "ilities", such as flexibility, commonality, reliability, maintainability, durability, scalability, safety, recyclability, and so on, with sustainability as the "holistic, if not overarching goal" [Moses, 2004a, p. 12].

The Stakeholder Networks can also be divided into four columns, from right to left: Need, Value, Individual Evaluation, and Group Decision, which represent the normal process for each stakeholder to make decisions related to the Large Engineering Projects. Specifically, stakeholder needs often provide engineers the intent of design, and once the physical architectures come into being, each stakeholder will usually have different perception for the (immediate and life-cycle) value of the Large Engineering Projects. Finally, the collective feedback from the Stakeholder Networks to the Large Engineering Projects generally takes the form of group decisions, after multi-round negotiations

influenced by the value perception and decision power of each stakeholder. Note that from the perspective of SVN, stakeholders' power is the confluence of both exchange relationships and network structures, as demonstrated by the Project Phoenix case in Chapter 4. Moreover, corresponding to the organizational hierarchies of each stakeholder, which are discussed through the China case in Chapter 6, stakeholders' specific needs, value perceptions, individual evaluations, and group decisions can also be classified into different levels, as emphasized by Keeney and Raiffa [1976, p. 44].

On the basis of the above reasoning, three meta-flows, namely, Architecture Design, Architecture Selection, and Architecture Iteration, finally connect Stakeholder Networks and Large Engineering Projects into the Stakeholder-Oriented Architecting Process. Note that the whole process should not be interpreted as a static, linear, and one-time phenomenon, but instead a dynamic, interactive, and iterative one.

In addition to its explanatory power, Figure A-1-1 also delivers two important messages as both challenges and opportunities for engineers, managers, and policymakers around the Large Engineering Projects:

- **Mapping between the Hierarchies of Objective, Organization, and Architecture:** (1) First and foremost, as “one of the central structural schemes that the architect of complexity uses” [Simon, 1962, p. 468], hierarchy is a common characteristics of objectives, stakeholders, and physical architectures. More specifically, engineers are knowledgeable about the architectural hierarchy shown on the right of Figure A-1-1; managers or decision analysts apply the hierarchy of multiple objectives to construct multi-attribute utility functions and inform the value trade-offs, as shown on the left of Figure A-1-1; and Chapter 6 in this dissertation, joined by organization scholars and social scientists, demonstrates the necessity to understand the organizational hierarchy of large and important stakeholders. However, a complete mapping between these types of hierarchies is still missing in many studies and practices, and arguably, this often causes the complexity across different domains cannot be fully understood

and effectively coped in a holistic way. (2) In the real world, stakeholders often express their needs abstractly on the highest level but root their value perceptions into the form attributes on the lowest level, as shown in Figure A-1-1. Actually, such a disparity often brings the difficulty (for both managers and engineers) to keep a logical consistency between the priority of stakeholder needs and the importance of form attributes. Therefore, it is important to explore the hierarchies of stakeholder objective and system architecture, and then link them at the same level. (3) In addition, as shown by the China case in Chapter 6, “the significant problems we face cannot be solved at the same level of thinking we were at when we created them”—if it is hard to analyze the stakeholder needs, values, positions, and decisions on one specific level, researchers and practitioners may want to shift their analysis into other levels to gain additional insights, by method of decision tools such as the AHP (Analytic Hierarchy Process).

- **Developing A Common Language, Framework, and Methodology:** Along the three meta-flows, that is, Architecture Design, Architecture Selection, and Architecture Iteration, Figure A-1-1 also attaches a non-exhaustive list of the (currently) available theories and methods to each process. For example, during the process of Architecture Design, system modeling is the traditional and primary approach for engineers to specify the space of architecture alternatives and compute the attributes of those alternatives—available methods include the OPN (Object-Process Network), DSM (Design Structure Matrix), DOE (Design of Experiments), and so on. However, the theories and methods for different processes are often developed for their own purpose and therefore come up in a fragmented way in Figure A-1-1. It would be difficult but well worthwhile to build the interfaces between those theories and methods, so that engineers, managers, and policymakers can share a common language, framework, and methodology to tackle with these tough problems together—the SVN analysis developed in this dissertation contributes to such an effort.

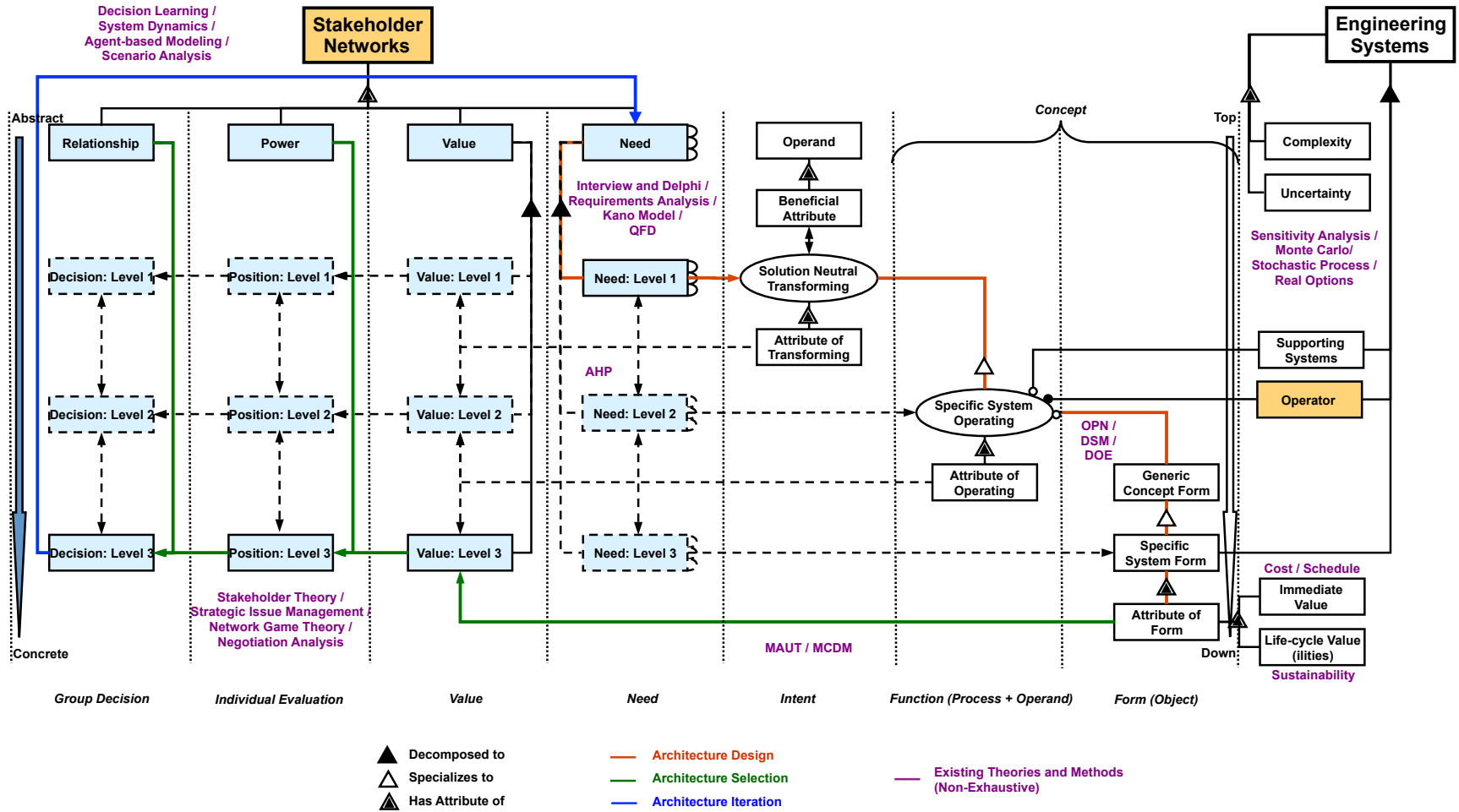


Figure A-1-1: Stakeholder-Oriented Architecting Process

A.3 Value Exchange Rates and Matrix

The other method, this Appendix shall propose now, is the Value Exchange Rates and Matrix, based on further extension of the common framework in the SVN analysis for both economic and social exchanges.

A.3.1 Theoretical Basis

As discussed in Chapter 2, for economic exchanges, Rational Choice Theory, which can be simply put as the principle of maximizing benefits and minimizing costs, is the dominant theoretical paradigm in microeconomics to explain exchange behavior of individuals or organizations.

On the basis of Social Exchange Theory (SET), the SVN analysis in this dissertation reduces both social and economic relationships to exchanges, through combining Rational Choice Theory (subjective cost-benefit analysis to be specific) and Behaviorist Psychology (comparison of alternatives to be specific). Under such a framework, “concepts and principles borrowed from microeconomics” [Cook, 2000, p. 687] can be applied to conduct “the economic analysis of noneconomic social situations” [Emerson, 1976, p. 336].

Exchange rates are clearly a widely used concept in microeconomics. In this section, this concept will be borrowed to include the exchanges mediated by natural and technological factors, in addition to the social and economic exchanges mediated by nonmarket and market environments, as discussed throughout previous chapters. Arguably, these natural and technological factors, such as the ratios from *Oil* to *CO₂* in the energy industry, are also critical for the overall performance of Large Engineering Projects.

A.3.2 Example and Definitions

For a better understanding, this section uses the Large Oil Projects (LOP hereafter) as an example to explain the definitions of the Value Exchange Rates and Matrix, as well as to elaborate their implications.

Figure A-1-2 illustrates a simplified exchange model for the LOP. Similar to the Stakeholder-Oriented Architecting Process discussed before, such an exchange model is distinguished from other existing models by the inclusion of exchanges between stakeholder network, physical architecture, and natural environment. Note that the stakeholder network shown in Figure A-1-2 is a subset of the SVN in previous chapters, because only those “architecturally significant” value flows are included.

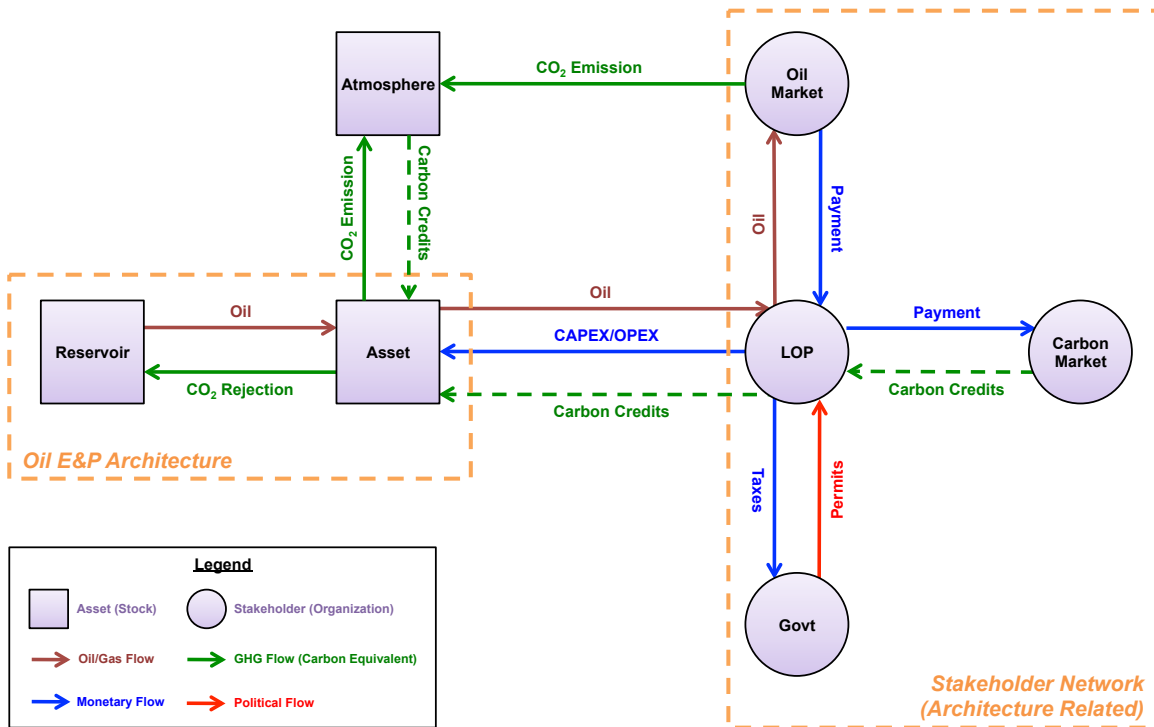


Figure A-1-2: Simplified Exchange Model for the LOP

Based on the example in Figure A-1-2, the definitions of Value Exchange Rates are summarized in Table A-1-1, and Figure A-1-3 maps these definitions back to the simplified exchange model for the LOP.

Further, Figure A-1-4 visualizes the structure between different exchange rates as a Value Exchange Matrix.

Table A-1-1: Definitions of Value Exchange Rates for the LOP

Exchange Rate No.	From	To	Definition	Mediator / Driver
1	Oil	CO ₂	$\frac{CO_2EMISSION_ASSET + CO_2REJECTION_ASSET}{Oil_RESERVOIR}$	Archi / Tech
2	Oil	Money	$\frac{Payment_OILMARKET}{Oil_LOP}$	Oil Market
3	Oil	Permit	$\frac{Tax_OIL}{Payment_OILMARKET}$	Institutions
4	CO ₂	Oil	$\frac{Oil_RESERVOIR}{CO_2REJECTION_ASSET}$	Reservoir
5	CO ₂	Money	$\frac{Payment_LOP}{CarbonCredits_CARBONMARKET}$	Carbon Market
6	CO ₂	Permit	$\frac{Tax_CARBON}{Payment_OILMARKET}$	Institutions
7	Money	Oil	$\frac{Oil_ASSET}{CAPEX_LOP + OPEX_LOP}$	Archi / Tech
8	Money	CO ₂	$\frac{CarbonCredits_CARBONMARKET}{Payment_LOP} = \frac{1}{ExchangeRate_5}$	Carbon Market
9	Money	Permit	$\frac{Tax_CAPEX}{Payment_OILMARKET}$	Institutions
10	Permit	Oil	$\frac{Payment_OILMARKET}{Tax_OIL} = \frac{1}{ExchangeRate_3}$	Institutions
11	Permit	CO ₂	$\frac{Payment_OILMARKET}{Tax_CARBON} = \frac{1}{ExchangeRate_6}$	Institutions
12	Permit	Money	$\frac{Payment_OILMARKET}{Tax_CAPEX} = \frac{1}{ExchangeRate_9}$	Institutions

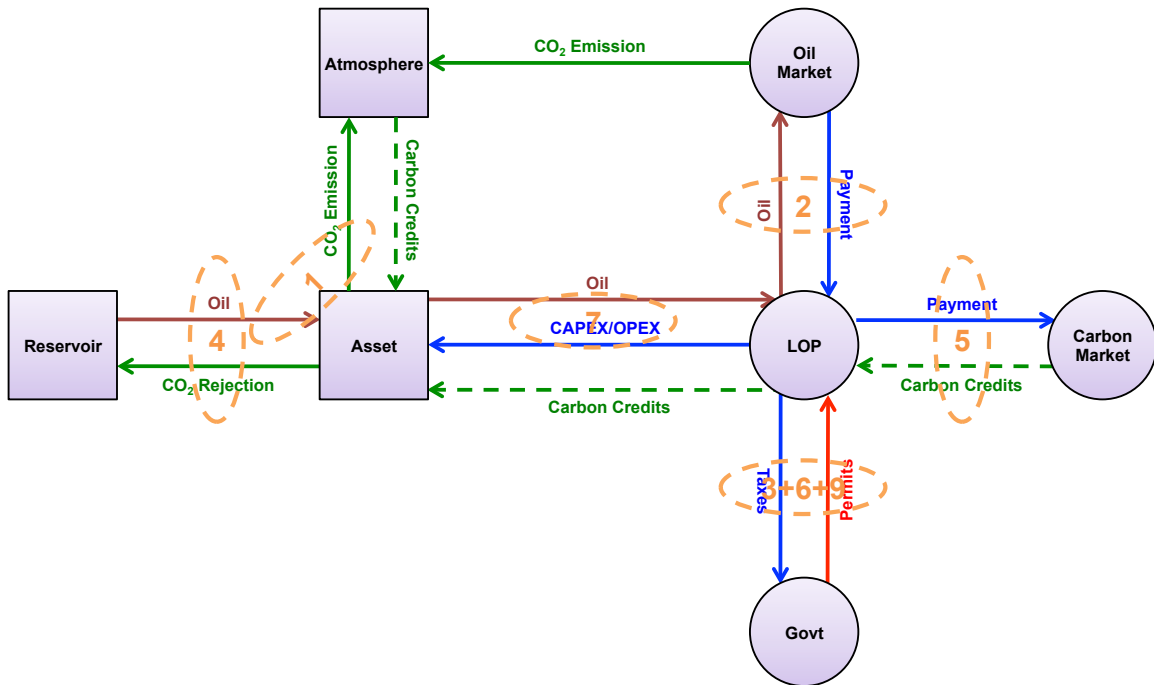


Figure A-1-3: Mapping between Value Exchange Rates and the Exchange Model

	Oil (bbl)	CO ₂ (tonne)	Money (US \$)	Permit
Oil (bbl)	1	CO ₂ Production Rate	51*	Oil Tax Rate
CO ₂ (tonne)	Gas Oil Ratio (GOR)	1	15**	Carbon Tax Rate
Money (US \$)	CAPEX and OPEX	1/15	1	CAPEX Tax Rate
Permit	1/Oil Tax Rate	1/Carbon Tax Rate	1/CAPEX Tax Rate	1

Note:

- Exchanges in Blue Blocks are mediated by (Oil and Carbon) Market; while Exchanges in Red, Green, and Grey Blocks are mediated by Institutions, Architecture/Technology, and Reservoir respectively (all are Nonmarket);
- Crude Oil Price (*, 03/19/2009) from: <http://www.bloomberg.com/markets/commodities/energyprices.html>;
- Carbon Price (**, 03/19/2009) from: <http://www.ecx.eu/> and <http://www.x-rates.com/calculator.html>.

Figure A-1-4: Value Exchange Matrix for the LOP

A.3.3 Observations and Applications

By defining two kinds of nodes (viz., stakeholder and asset) and four types of flows (viz., oil and gas, GHG, monetary, and political), the simplified exchange model bridges the gap between stakeholder network and physical architecture for the Large Engineering Projects. With this method, it becomes possible to better understand how the technical decisions will impact the stakeholder relationships, as well as how to apply such an understanding to inform better decisions on architecture design and selection.

For the Value Exchange Rates and Matrix, more specific applications may include:

- **Aligning Stakeholders' Interest:** With the “generalized” Value Exchange Rates defined between *Oil*, *CO₂*, *Money*, and *Permit*, the traditional results from system architecting model can be propagated into the stakeholder network and then the costs/benefits (debits/credits) for each stakeholder are possible to be calculated. Based on a trade-off analysis for these costs/benefits, good architectures, which align the stakeholders' interest, can be better identified.
- **Adding Time Dependence:** The concept of Value Exchange Rates can easily integrate the temporal dimension (time dependence) into analysis: How will the costs/benefits (debits/credits) and stakeholders' interest change with time? How can stakeholders' temporal preference (discount rate) be described (exponential or hyperbolic)?
- **Analyzing Network Performance:** With the costs/benefits (debits/credits) profile of each stakeholder, the distribution of resources/pollutions throughout the stakeholder network can be analyzed, and further, the network performance (robustness, stability, etc.) in terms of specific criteria (efficiency, equity, etc.) can also be evaluated.
- **Capturing Major Drivers:** The Value Exchange Matrix (see Figure A-1-4) identifies the major drivers (mediators) for both physical architecture and stakeholder network, and also visualizes the structure of these drivers. It would

be interesting to study the properties of these drivers as well as to test the dependence of stakeholders' interest and network performance on them.

A.4 Summary

Based on the complete framework of the SVN analysis, this Appendix conceives two innovative methods, namely, Stakeholder-Oriented Architecting Process and Value Exchange Rates & Matrix, to bridge the gap between the SVN analysis and Systems Architecting, so that the synergy between stakeholder management and system design can be achieved to ensure the long-term success of large engineering projects in a complex and dynamic socio-technical environment.

Currently these two methods are still in the stage of conceptual development, and therefore more research along with empirical observations and case studies for these methods are much desired.

APPENDIX II: SUPPLEMENTAL MATERIALS

Questionnaire A-3-1: Stakeholder Questionnaire for the Multinational Energy Project

INSTRUCTIONS:

The intent of this survey is to develop insight into the needs of stakeholders and how they are fulfilled. We have identified a number of stakeholders that interact with each other. We have identified a number of needs that each particular stakeholder may have. This survey seeks to characterize the nature of the needs of each stakeholder, as well as their preferred source of fulfillment.

The following pages of the survey contain a series of questions regarding the needs of each stakeholder, divided into sections by stakeholder. **In answering the questions, it is important that you try to think of yourself as a representative from that particular stakeholder group.** For each identified need, there are two questions.

The 4th column labeled “Intensity of Need” asks you to characterize both the “satisfaction” of fulfillment, as well as the “regret” you feel when the need goes unfulfilled. Use the first scale below to characterize each in as: A, B, C, D, or E. In the 5th column labeled “Importance of Source” you are asked to evaluate how much benefit or utility you derive from having a particular source fulfill that need. Use the second scale below to characterize each in as: 1, 2, 3, 4, or 5. In some instances there is more than one source capable of fulfilling a need, and you will be asked to provide feedback on each source individually.

Please check the box that corresponds to your response to each question in the questionnaire. Although your feelings on a particular need or source may be described by more than one answer, please select the one that BEST describes how you feel. You may wish to print out the Question box below to refer to while you complete the survey.

Thank you for taking the time to complete the survey!

Intensity of Need:

How would you characterize the presence/absence of fulfillment of this need?

- A. I would be satisfied by its presence, but I would not regret its absence
- B. I would be satisfied by its presence, and I would somewhat regret its absence
- C. I would be satisfied by its presence, and I would regret its absence
- D. Its presence is necessary, and I would regret its absence
- E. Its presence is absolutely essential, and I would regret its absence

Importance of Source:

If this need were to be fulfilled, how important would this source be in fulfilling the need?

- 1. Not important – I do not need this source to fulfill this need
- 2. Somewhat important – It is acceptable that this source fulfills this need
- 3. Important – It is preferable that this source fulfills this need
- 4. Very important – It is strongly desirable that this source fulfills this need
- 5. Extremely important – It is indispensable that this source fulfills this need

TO	VALUE FLOW	FROM	INTENSITY OF NEED					IMPORTANCE OF SOURCE					COMMENTS
			A	B	C	D	E	1	2	3	4	5	
Project	Project Approval												
	Regulatory Approval	Host-Country Government											
	Technology	Local Community											
	Workforce	Enterprise											
	Logistic Support	Local Community											
	Product Subsystems	Host-Country Corporation											
	Investment	Suppliers											
		Enterprise											
	Enterprise	Future Project Approval											
Technology Requirements		Host-Country Government											
High-grade Goods		Project											
Low-grade Goods		Project											
Investment		Project											
Sales Revenue		Investors											
		Consumers											
Host-Country Corporation		Technology Transfer											
	Revenue Sharing	Project											
	Economic Support	Project											
		Host-Country Government											
Host-Country Government	Political Influence												
	Project Lobbying	Host-Country Corporation											
	Taxes	Local Community											
		Project											
Local Community	Federal Support												
	Policy Support	Host-Country Government											
	Environmental Compliance	NGO											
	Employment	Project											
		Project											
Investors	ROI												
	Enterprise												
Consumers	Product												
	Enterprise												
Suppliers	Contracts												
	Project												
NGO	Environmental Impact Plan												
	Project												

Table A-4-1: Value Flow Definitions for Project Phoenix

To	From	Value Flow	Description
PROJECT PHOENIX (PP)	Feedstock Country Transportation (FCT)	Transportation Facilities	Construction and maintenance of facilities transporting chemical feedstock from another country to PROJECT PHOENIX, which is located in the host state.
	Feedstock Country Producers (FCP)	Chemical Feedstock	Chemical feedstock provided by Feedstock Country Producers to PROJECT PHOENIX as raw materials.
	Contractors/Suppliers/3 rd Parties (CSP)	Equipment and Service	Equipment provided by suppliers, such as the chemical treatment facilities; and service provided by contractors, such as the construction of new factory.
	Host State Government (HSG)	Local Permits	Permits issued by the Environmental Protection Agency of Host State Government for PROJECT PHOENIX.
	International Finance (INF)	Investment	Partial investment on PROJECT PHOENIX will come from international finance, such as large investment banks.
	Local Public (LOP)	Payment	Revenue from selling chemical products from PROJECT PHOENIX to local people.
	Local Public (LOP)	Technology Awareness	The awareness from local people for the environmental-friendly technology, which will be used in PROJECT PHOENIX.
	New Technology Generators (NTG)	New Technology	Specific technology developed to improve the environmental performance of PROJECT PHOENIX, such as the add-on equipment to reduce pollutant emissions.
	New Technology Generators (NTG)	Technology Assurance	The assurance for the capacity of new technology, especially for its environmental performance, which should meet both local and national environmental permits.
	NGO (NGO)	Environmental "Approval"	Positive feedback from NGO on the environmental feasibility of PROJECT PHOENIX.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. PROJECT PHOENIX will use them to judge the standpoints of other stakeholders and take corresponding measures.
	U.S. Federal Government (UFG)	National Permits	Permits issued by the U.S. Environmental Protection Agency (EPA) for PROJECT PHOENIX.
Local Governans. (LG)	PROJECT PHOENIX (PP)	Environmental Compliance	Evidence that PROJECT PHOENIX is complying with the supervision from local governments on its environmental impacts.
	PROJECT PHOENIX (PP)	Economic Stimulation	The direct and indirect stimulus of the local economy by PROJECT PHOENIX, such as more job opportunities, cheaper chemical products, etc.
	PROJECT PHOENIX (PP)	Taxes	Local taxes paid by PROJECT PHOENIX.

	Adjacent State Representatives (ASR)	Political Support	Favorable feelings and support from Adjacent State Representatives to the local governments, such as favorable policy for economic development.
	Host State Government (HSG)	Political Support	Favorable feelings and support from Host State Government to the local governments, such as favorable policy for economic development.
	Local Public (LOP)	Support	Approval by the people for their local governments, such as votes for the election of local government officers.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. Local governments will use them to adjust their opinions on the project.
Host State Government (HSG)	PROJECT PHOENIX (PP)	Taxes	State taxes paid by PROJECT PHOENIX.
	Local Governments (LOG)	Political Influence	The decisions of Host State Government on PROJECT PHOENIX may be influenced by local governments, through lobby or other ways.
	Local Governments (LOG)	Regulatory Compliance	Evidence that local governments are complying with all the regulations issued by Host State Government, such as the emission permits for PROJECT PHOENIX.
	Local Public (LOP)	Support	Approval by the people for Host State Government, such as votes for the election of State Congress and Executives.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. Host State Government will use them to adjust its opinions on the project.
	U.S. Federal Government (UFG)	Boundary Conditions	The conditions stated by U.S. Federal Government, regarding the land boundary between host state and its adjacent state. Those conditions will significantly change the right / responsibility of each state on PROJECT PHOENIX.
	U.S. Federal Government (UFG)	Political Influence	The U.S. Federal Government influences Host State Government with regard to laws and policy, for example to adopt stricter permits on environmental emissions.
Adjacent State Reps. (ASR)	Local Governments (LOG)	Political Influence	The decisions of Adjacent State Representatives may be influenced by local governments, through lobby or other ways.
	Local Governments (LOG)	Regulatory Compliance	Evidence that local governments are complying with all the regulations issued by Host State Government, such as the emission permits for PROJECT PHOENIX.
	Local Public (LOP)	Support	Approval by the people for Adjacent State Representatives, such as votes for the election of the Congressmen and Senators for the adjacent state.

	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. Adjacent State Representatives will use them to adjust their opinions on the project.
U.S. Federal Govern (UFG)	PROJECT PHOENIX (PP)	Security	PROJECT PHOENIX will provide the U.S. the security on national strategy supply.
	PROJECT PHOENIX (PP)	Taxes	National taxes paid by PROJECT PHOENIX.
	Feedstock Country Government (FCG)	Influence	The U.S. policies and regulations may be influenced by Feedstock Country Government, through the political and economic collaboration between these two countries.
	Adjacent State Representatives (ASR)	Political Influence	Adjacent State Representatives may play their roles in the U.S. Congress to influence national policies and regulations, such as the permits for PROJECT PHOENIX.
	Local Public (LOP)	Support	Approval by the people for the U.S. Federal Government, such as votes for the Presidential election.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. U.S. Federal Government will use them to adjust its opinions on the project.
Feedstock Country Govern (FCG)	Feedstock Country Transportation (FCT)	Taxes	Taxes paid by Feedstock Country Transportation, from the revenue by transporting chemical feedstock to PROJECT PHOENIX.
	Feedstock Country Producers (FCP)	Taxes	Taxes paid by Feedstock Country Producers, from the revenue by selling chemical feedstock to PROJECT PHOENIX as raw materials.
	U.S. Federal Government (UFG)	Influence	Similar to the above, the policies and regulations in the feedstock country may also be influenced by U.S. Federal Government, through the political and economic collaboration between these two countries.
Feedstock Country Transportation (FCT)	PROJECT PHOENIX (PP)	Payment	Revenue from transporting chemical feedstock to PROJECT PHOENIX.
	Feedstock Country Government (FCG)	Regulations	Specific regulations issued by Feedstock Country Government, regarding construction, safety, environmental performance and other aspects related to the transportation of chemical feedstock.
	Feedstock Country Government (FCG)	Support	As an important tax contributor, Feedstock Country Transportation needs the political and economic support from Feedstock Country Government, such as beneficial policy and direct investment.
	U.S. Federal Government (UFG)	Regulations	Specific regulations issued by U.S. Federal Government, regarding construction, safety, environmental performance and other aspects related to the transportation of chemical feedstock.

Feedstock Country Producers (FCP)	PROJECT PHOENIX (PP)	Payment	Revenue from selling chemical feedstock to PROJECT PHOENIX as raw materials.
	Feedstock Country Government (FCG)	Support	As an important tax contributor, Feedstock Country Producers need the political and economic support from Feedstock Country Government, such as beneficial policy and direct investment.
New Tech Generators (NTG)	PROJECT PHOENIX (PP)	Payment	Revenue by selling modern pollution-control technology to PROJECT PHOENIX, such as the add-on equipment to reduce pollutant emissions.
	PROJECT PHOENIX (PP)	Tech Demand	The demand from PROJECT PHOENIX for the pollution-control technology development by outside generators, such as economic cost and environmental performance of the technology.
Contractors/Suppliers/3 rd Parties (CSP)	PROJECT PHOENIX (PP)	Payment	Revenue from selling equipment or providing service for PROJECT PHOENIX.
	PROJECT PHOENIX (PP)	Specifications	The detailed requirements for the equipment and service needed by PROJECT PHOENIX, such as equipment specification or construction blueprint.
Local Public (LOP)	PROJECT PHOENIX (PP)	Economic Stimulation	The direct and indirect promotion of the local economy by PROJECT PHOENIX, such as more job opportunities, cheaper chemical products, etc.
	PROJECT PHOENIX (PP)	Employment	PROJECT PHOENIX will create thousands of construction jobs over five-year period and a few hundred new full-time positions once the construction is complete.
	PROJECT PHOENIX (PP)	Environmental Mitigation	Evidence that PROJECT PHOENIX will / is minimize(ing) its pollution from the existing facility as well as from the new facilities.
	PROJECT PHOENIX (PP)	Chemical Products	PROJECT PHOENIX will bring a huge amount of chemical products to the adjacent areas of the U.S. every year.
	PROJECT PHOENIX (PP)	Local Infrastructure	PROJECT PHOENIX will build more useful infrastructure for local people. In addition, this project will also bring about many other living establishments for more employees, including supermarket, hospital, restaurant, residence area, etc.
	Contractors/Suppliers/3 rd Parties (CSP)	Employment	The contractors / suppliers / 3 rd parties involved in PROJECT PHOENIX will also provide employment opportunities for local people, directly or indirectly.
	Local Governments (LOG)	Local Government Service	Local governments provide services for their people, such as health care, unemployment insurance, infrastructure maintenance, etc.
NGO (NGO)	Environmental Justice	Evidence that NGO's are maintaining environmental justice for local people. For example, NGO will fight for local people if their	

			life quality and the natural environment are threaten or harmed.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. Local public will use them to adjust their opinions on the project.
Public Media (PUM)	PROJECT PHOENIX (PP)	Opinions	The positive view from PROJECT PHOENIX, or PROJECT PHOENIX's argument against the negative feedback from other stakeholders.
	PROJECT PHOENIX (PP)	Tech Assurance Information	This is a subset of PROJECT PHOENIX's opinions, mainly referring to the technical information, which can prove the environmental capability of the project.
	Adjacent State Representatives (ASR)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from Adjacent State Representatives on PROJECT PHOENIX.
	Host State Government (HSG)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from Host State Government on PROJECT PHOENIX.
	International Finance (INF)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from the international finance on PROJECT PHOENIX.
	Local Governments (LOG)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from the local governments on PROJECT PHOENIX.
	Local Public (LOP)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from the local people on PROJECT PHOENIX.
	NGO (NGO)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from NGO on PROJECT PHOENIX.
	U.S. Federal Government (UFG)	Opinions	The specific view or feedback, which can be positive, negative or neutral, from the U.S. Federal Government on PROJECT PHOENIX.
NGO (NGO)	PROJECT PHOENIX (PP)	Information	NGO needs the environmental impact information from PROJECT PHOENIX to make assessment on the project, such as the indices for pollutant emissions.
	Host State Government (HSG)	Friendly Environmental Policy	Friendly environmental policy from Host State Government will help NGO protect the natural environment and life quality for local people. For example, setting the emission quota for PROJECT PHOENIX.
	Local Public (LOP)	Environmental Satisfaction	NGO needs the degree of satisfaction by the local community to make assessment on PROJECT PHOENIX. These data can be obtained through public survey.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. NGO will use them to adjust its opinions on the project.
	U.S. Federal Government (UFG)	Friendly Environmental Policy	Friendly environmental policy from the U.S. Federal Government will help NGO protect the natural environment and life quality for

			local people. For example, setting the emission quota for PROJECT PHOENIX.
International Finance (INF)	PROJECT PHOENIX (PP)	Profits	The monetary return for the investment from international finance on PROJECT PHOENIX.
	Public Media (PUM)	News	All positive and negative media coverage of PROJECT PHOENIX. International finance will use them to adjust its opinions on the project.

Table A-4-2: Stakeholder Questionnaire for Project Phoenix

TO STAKEHOLDER	VALUE FLOW	FROM STAKEHOLDER	URGENCY OF NEED (Check all that apply)					IMPORTANCE OF SOURCE (Check only one)						
			A	B	C	D	E	1	2	3	4	5		
Project Phoenix (PP)	Transportation Facilities	Feedstock Country Transportation												
	Raw Materials	Feedstock Country Producers												
	Equipment and Service	Contractors/Suppliers/3rd Parties												
	Local Permits	Host State Government												
	Investment	International Finance												
	Payment	Local Public												
	Tech Awareness	Local Public												
	New Tech	New Tech Generators												
	Tech Assurance	New Tech Generators												
	Environmental "Approval"	NGO												
	News	Public Media												
National Permits	U.S. Federal Government													
Local Governments (LOG)	Environmental Compliance	Project Phoenix												
	Economic Stimulation	Project Phoenix												
	Taxes	Project Phoenix												
	Political Support	Adjacent State Representatives												
	Political Support	Host State Government												
	Support	Local Public												
Host State Government (HSG)	News	Public Media												
	Taxes	Project Phoenix												
	Political Influence	Local Governments												
	Regulatory Compliance	Local Governments												
	Support	Local Public												
	News	Public Media												
	Boundary Conditions	U.S. Federal Government												
Political Influence	U.S. Federal Government													
Adjacent State Representatives (ASR)	Political Influence	Local Governments												
	Regulatory Compliance	Local Governments												
	Support	Local Public												
	News	Public Media												
U.S. Federal Government (UFG)	Strategy Supply Security	Project Phoenix												
	Taxes	Project Phoenix												
	Influence	Canadian Government												
	Political Influence	Adjacent State Representatives												
	Support	Local Public												
	News	Public Media												
Feedstock Country Government (FCG)	Taxes	Feedstock Country Transportation												
	Taxes	Feedstock Country Producers												
	Influence	U.S. Federal Government												
Feedstock Country Transportation (FCT)	Payment	Project Phoenix												
	Regulations	Canadian Government												
	Support	Canadian Government												
	Regulations	U.S. Federal Government												
Feedstock Country Producers (FCP)	Payment	Project Phoenix												
	Support	Canadian Government												
New Tech Generators (NTG)	Payment	Project Phoenix												
	Tech Demand	Project Phoenix												
Contractors/Suppliers/3rd Parties (CSP)	Payment	Project Phoenix												
	Specifications	Project Phoenix												
Local Public (LOP)	Economic Stimulation	Project Phoenix												
	Employment	Project Phoenix												
	Environmental Mitigation	Project Phoenix												
	Chemical Products	Project Phoenix												
	Local Infrastructure	Project Phoenix												
	Employment	Contractors/Suppliers/3rd Parties												
	Local Government Service	Local Governments												
	Environmental Justice	NGO												
Public Media (PUM)	News	Public Media												
	Opinions	Project Phoenix												
	Tech Assurance Info	Project Phoenix												
	Opinions	Adjacent State Representatives												
	Opinions	Host State Government												
	Opinions	International Finance												
	Opinions	Local Governments												
	Opinions	Local Public												
NGO (NGO)	Opinions	NGO												
	Opinions	U.S. Federal Government												
	Information	Project Phoenix												
	Friendly Environmental Policy	Host State Government												
	Environmental Satisfaction	Local Public												
International Finance (INF)	News	Public Media												
	Profits	Project Phoenix												
	News	Public Media												

Table A-4-3: Internal Assets Definitions for Project Phoenix

Stakeholder Characterization		Internal Assets for Value Flows	
<i>Category</i>	<i>Representatives</i>	<i>Name</i>	<i>Description</i>
Governments	LOG, HSG, ASR, UFG, FCG	Domestic Political Capital	Connecting the value flows that are generally related with favorable public image for the government, such as "Support from Local Public to Local Governments".
		Project Support	Connecting the value flows that are specifically related to the project, such as "Environmental Compliance from PROJECT PHOENIX to Local Governments".
		Treasury	Connecting the monetary value flows, such as "Taxes from PROJECT PHOENIX to Host State Government".
Commercial Sectors	PP, FCP, FCT, NTG, CSP, INF	Human Resource	Connecting the value flows for workforce and employment, such as "Employment from PROJECT PHOENIX to Local Public".
		CAPEX	Connecting the value flows related with fixed capital cost, such as "Facilities from Feedstock Country Transportation to PROJECT PHOENIX".
		OPEX	Connecting the value flows related with variable operation cost, such as "Chemical Feedstock from Feedstock Country Producers to PROJECT PHOENIX".
		Revenue	Connecting the value flows related with revenue from sales, such as "Payment from Local Public to PROJECT PHOENIX".
		Legal Eligibility	Connecting the value flows related with legal / regulatory / policy requirements for the companies, such as "National Permits from the U.S. Federal Government to PROJECT PHOENIX".
		Corporate Strategy	Connecting the value flows related with high-level or long-term benefits of the companies, such as "Security from PROJECT PHOENIX to the U.S. Federal Government".

Local Public	LOP	Financial Wellbeing	Connecting the monetary value flows in people's life, such as "Economic Stimulation from PROJECT PHOENIX to Local Public".
		Quality of Life	Connecting the value flows related with natural environment and other aspects important for people's life quality, such as "Environmental Mitigation from PROJECT PHOENIX to Local Public".
		Political Influence	Connecting the value flows for the generally relationships between local people and governments, such as "Local Government Service from Local Governments to Local Public".
		Project Support	Connecting the value flows that are specifically related to the project, such as "Chemical Products from PROJECT PHOENIX to Local Public".
NGO	NGO	Political Influence	Connecting the value flows related with the public role of NGO, such as "Environmental 'Approval' from NGO to PROJECT PHOENIX".
		Supporting Materials	Connecting the value flows supporting NGO to play its public role, such as "Environmental Satisfaction from Local Public to NGO".
Public Media	PUM	Informative Content	Connecting the value flows related with all positive and negative coverage of media on the project, such as "Tech Assurance Info from PROJECT PHOENIX to Public Media".

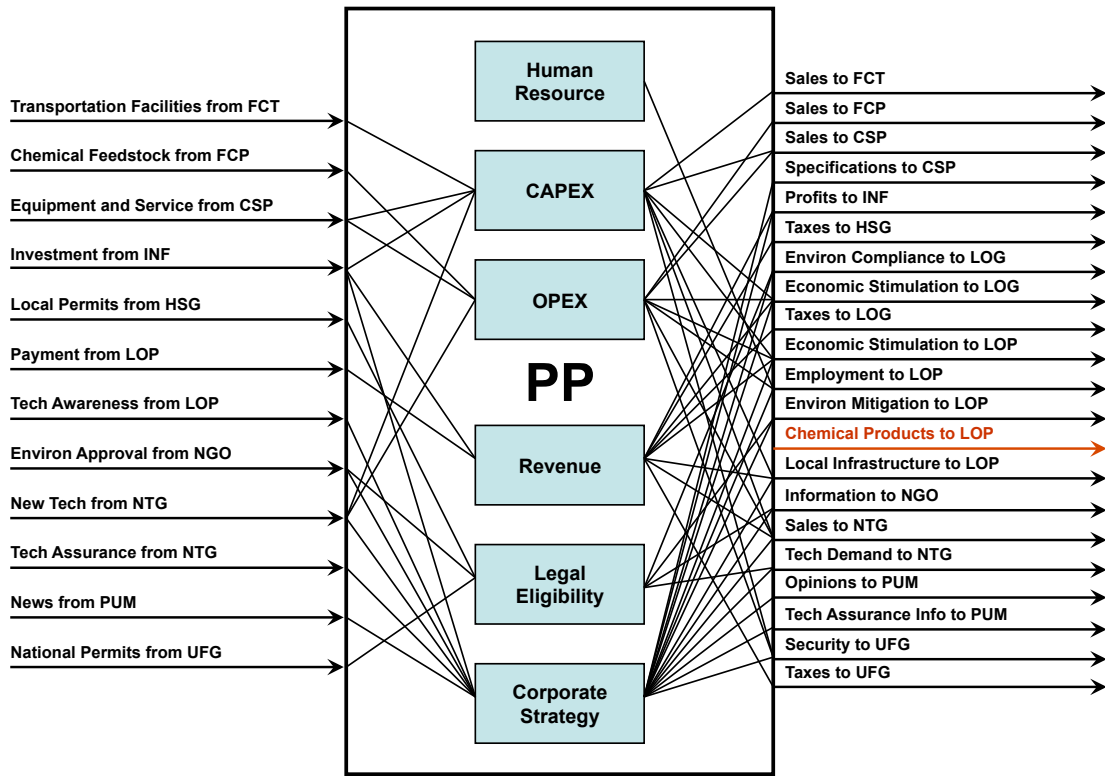


Figure A-4-1: Internal Assets Model for PP

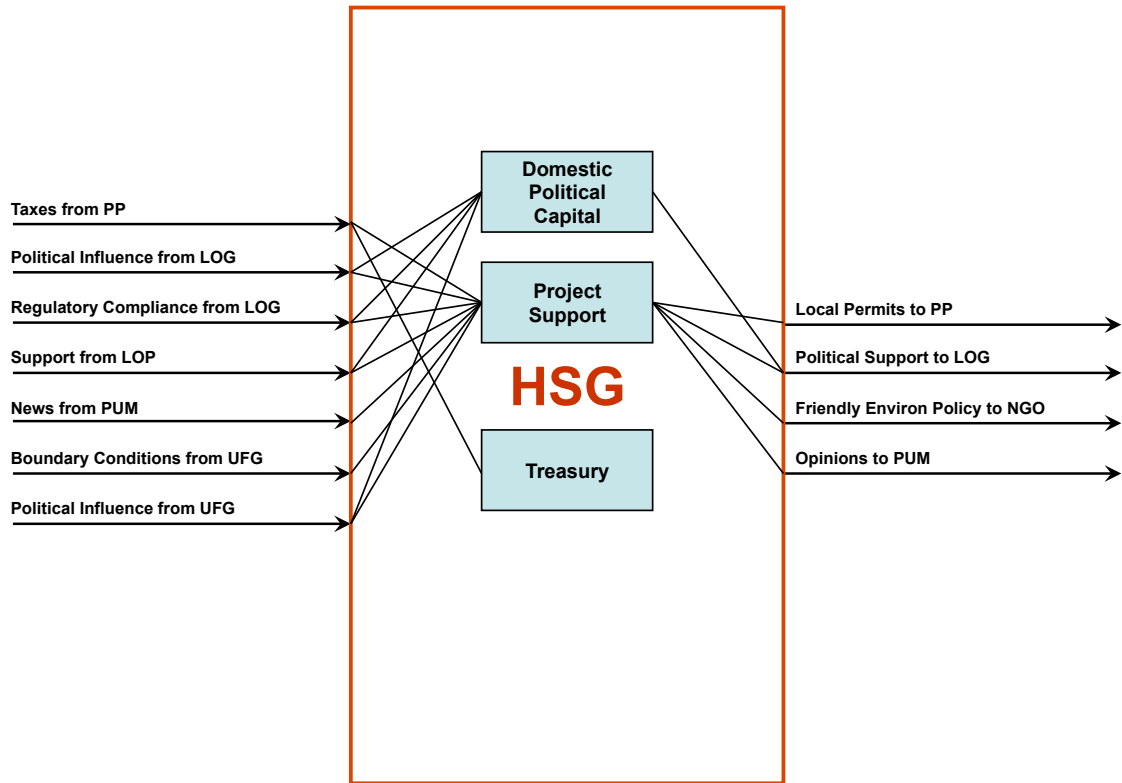


Figure A-4-2: Internal Assets Model for HSG

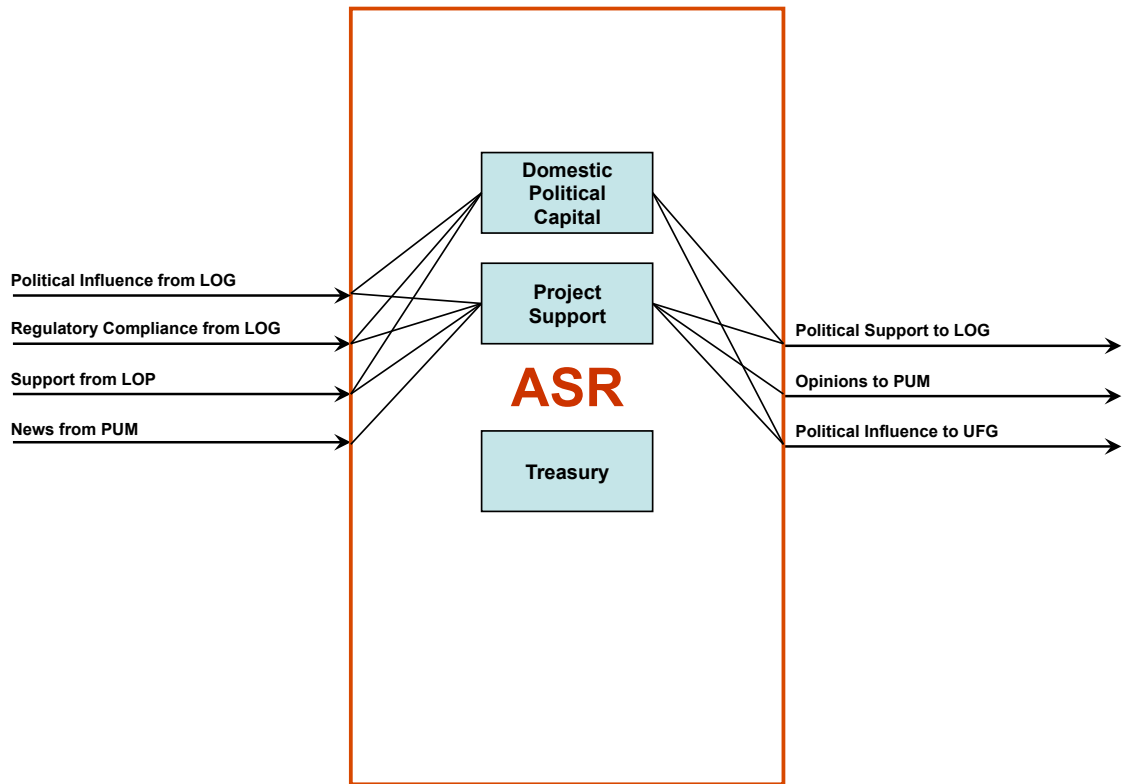


Figure A-4-3: Internal Assets Model for ASR

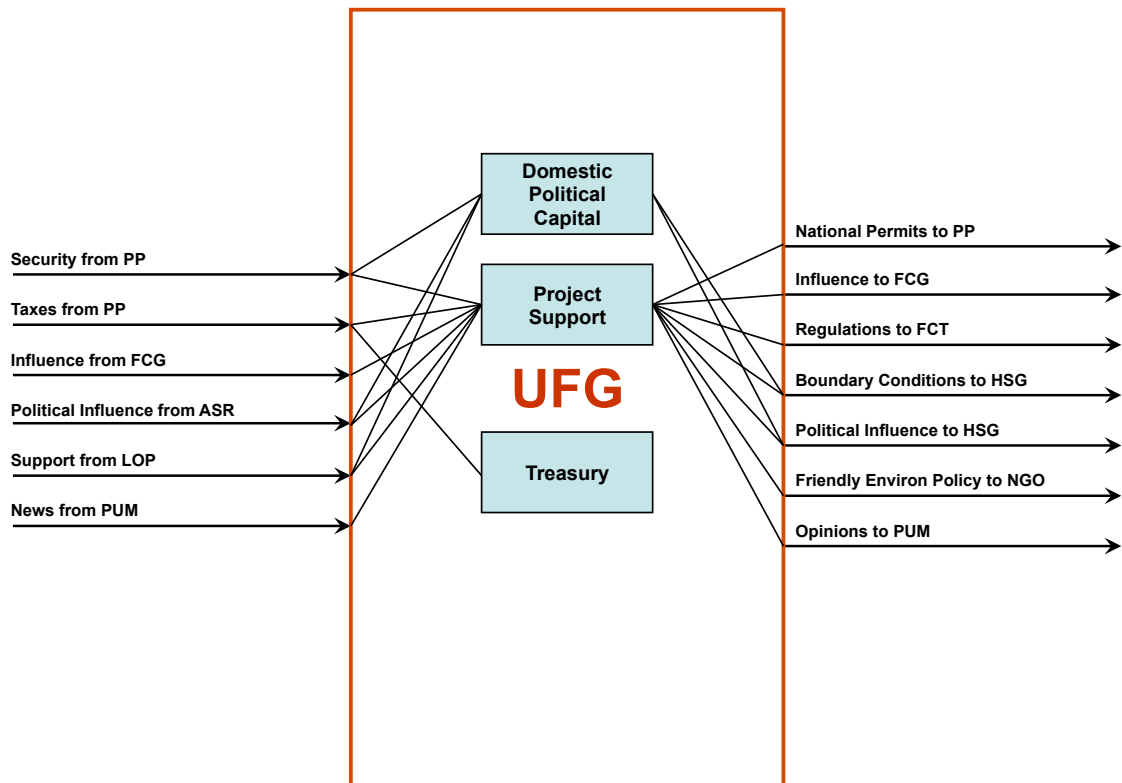


Figure A-4-4: Internal Assets Model for UFG

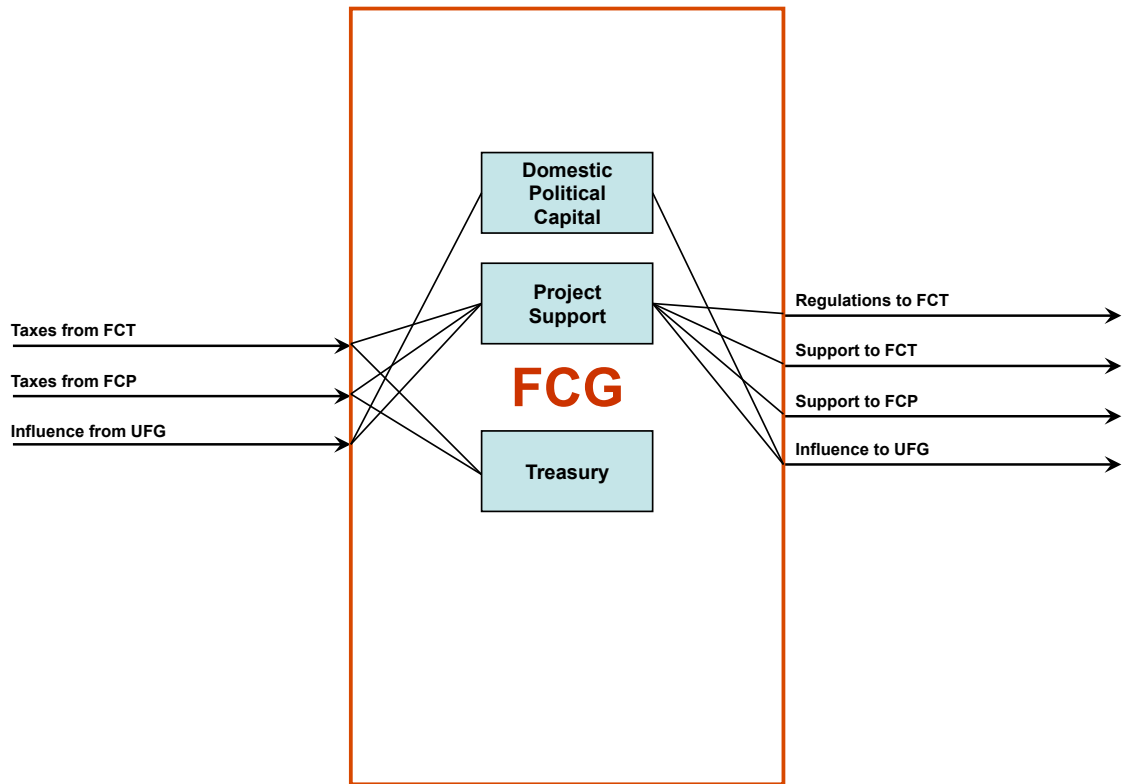


Figure A-4-5: Internal Assets Model for FCG

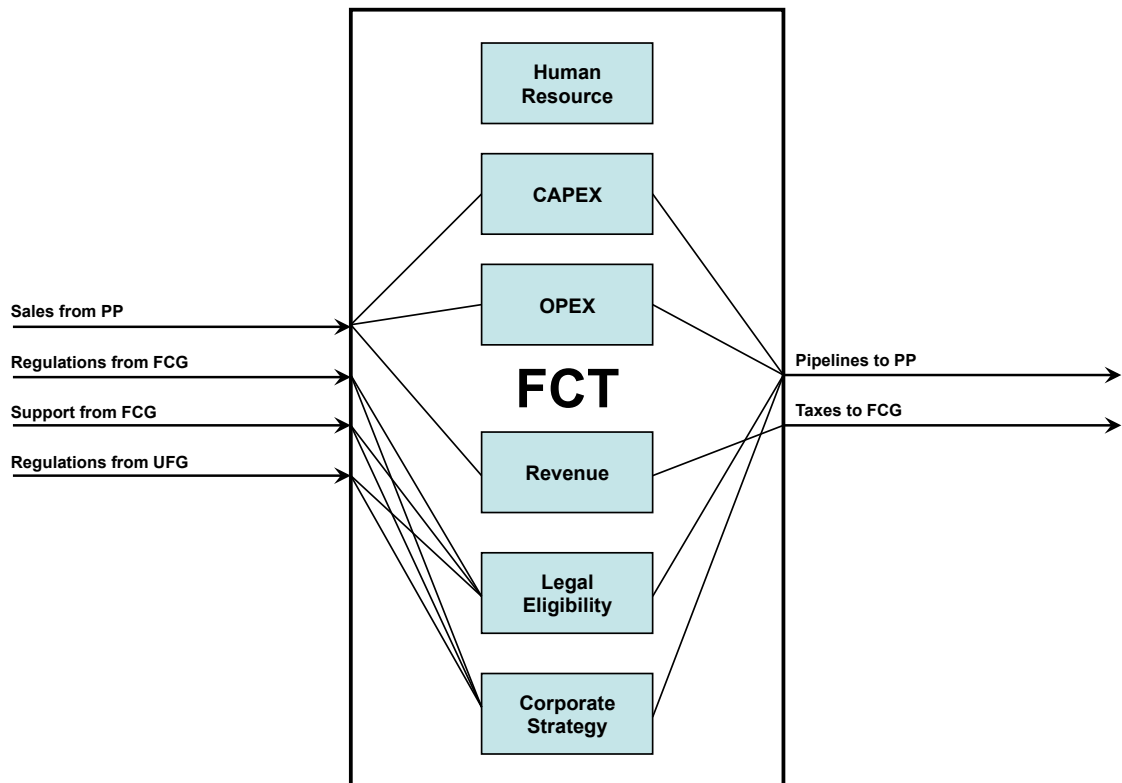


Figure A-4-6: Internal Assets Model for FCT

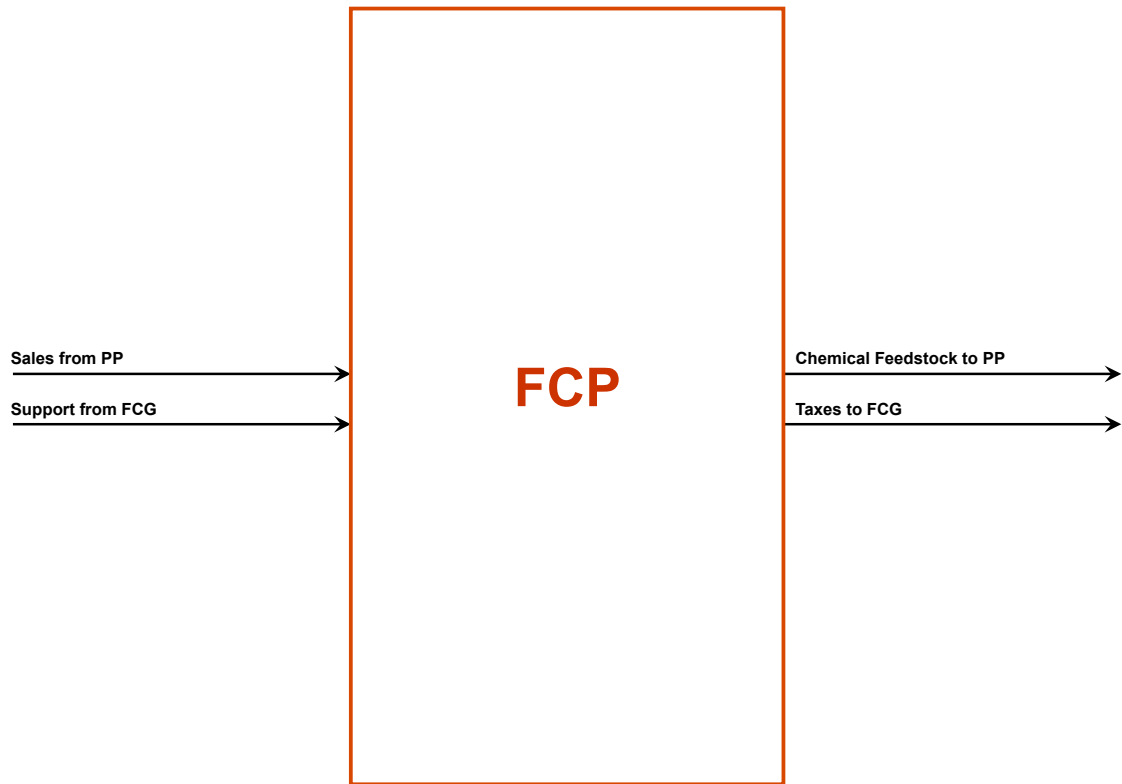


Figure A-4-7: Internal Assets Model for FCP

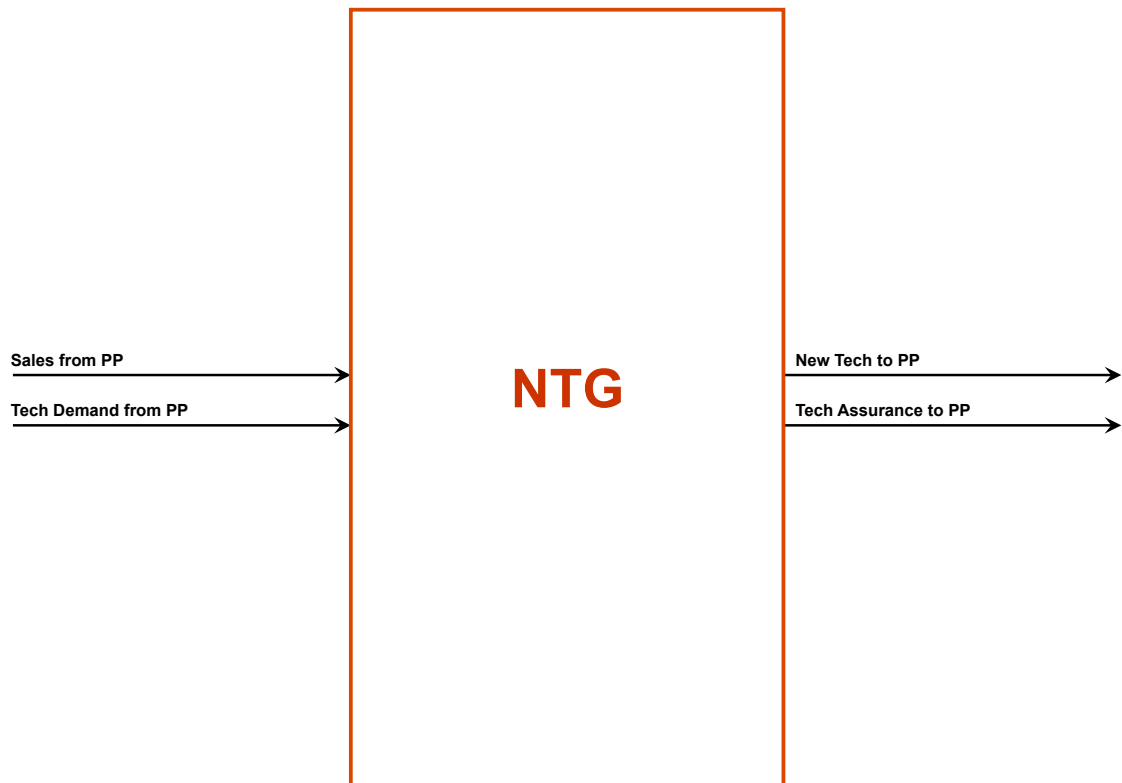


Figure A-4-8: Internal Assets Model for NTG

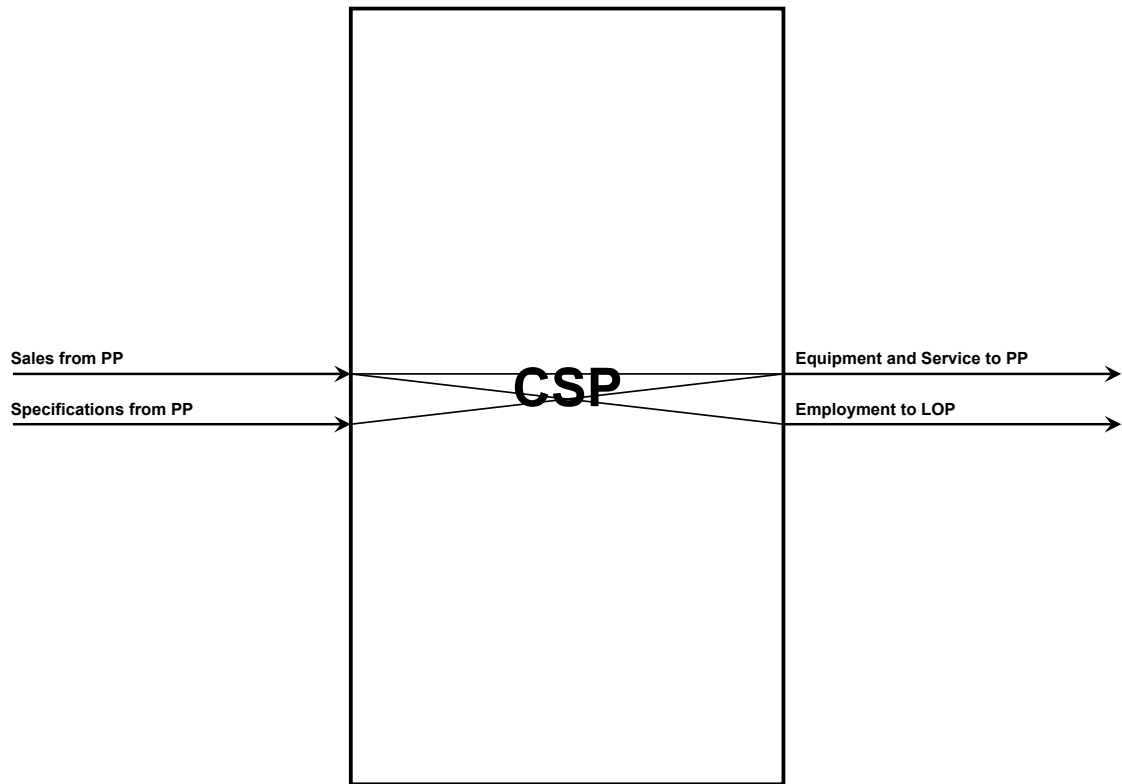


Figure A-4-9: Internal Assets Model for CSP

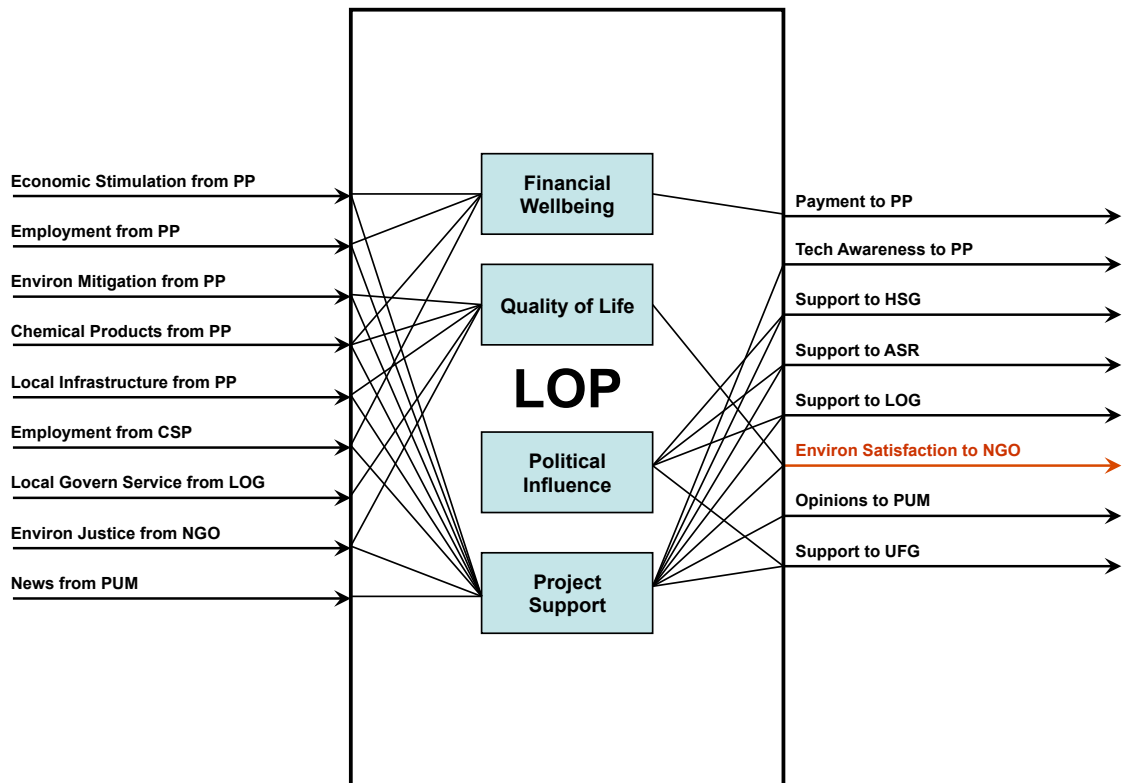


Figure A-4-10: Internal Assets Model for LOP

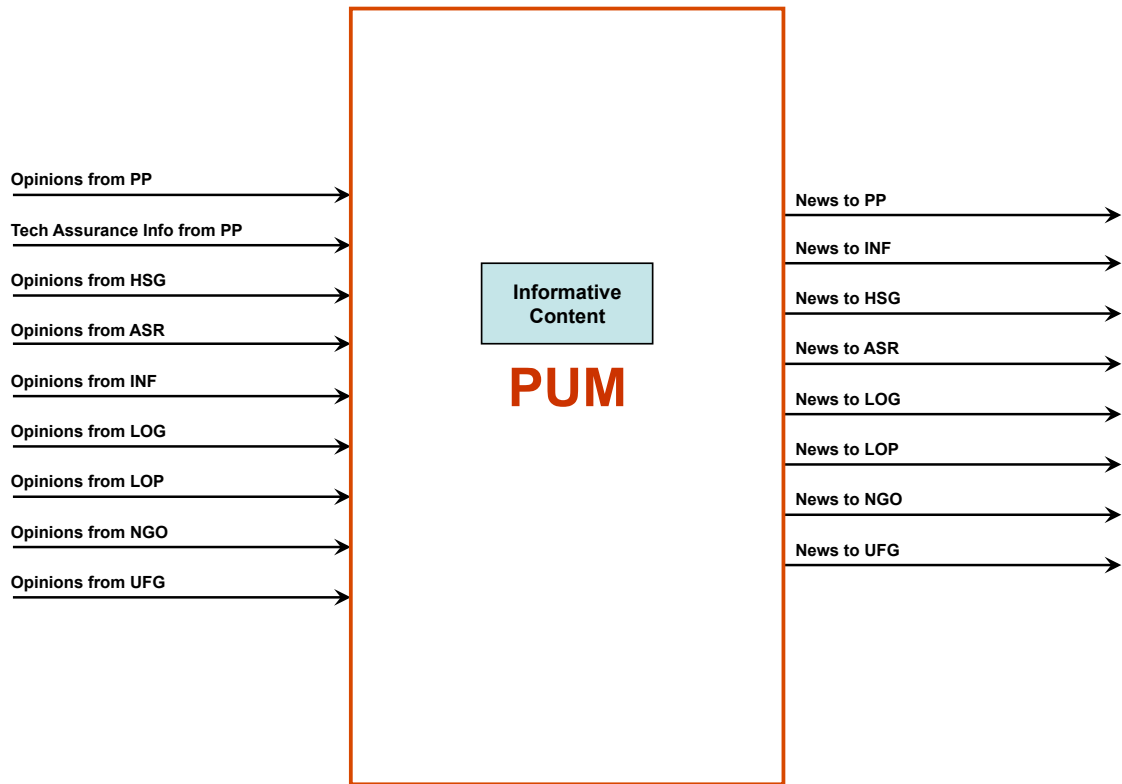


Figure A-4-11: Internal Assets Model for PUM

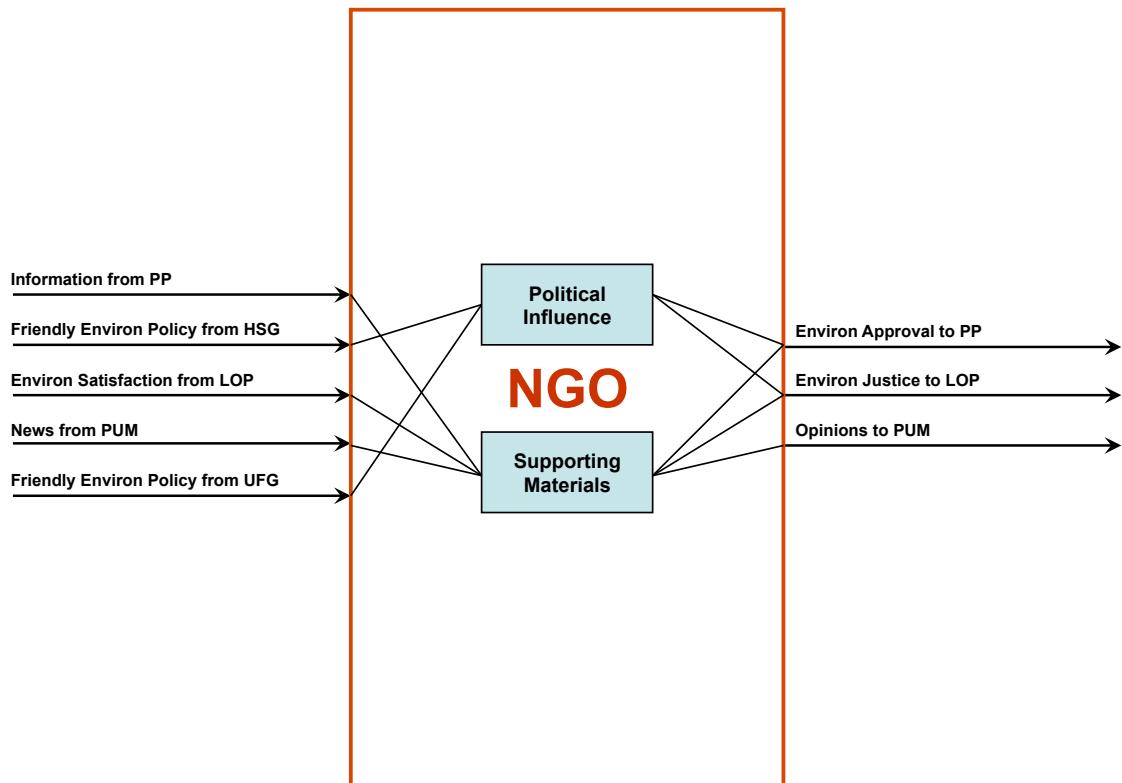


Figure A-4-12: Internal Assets Model for NGO

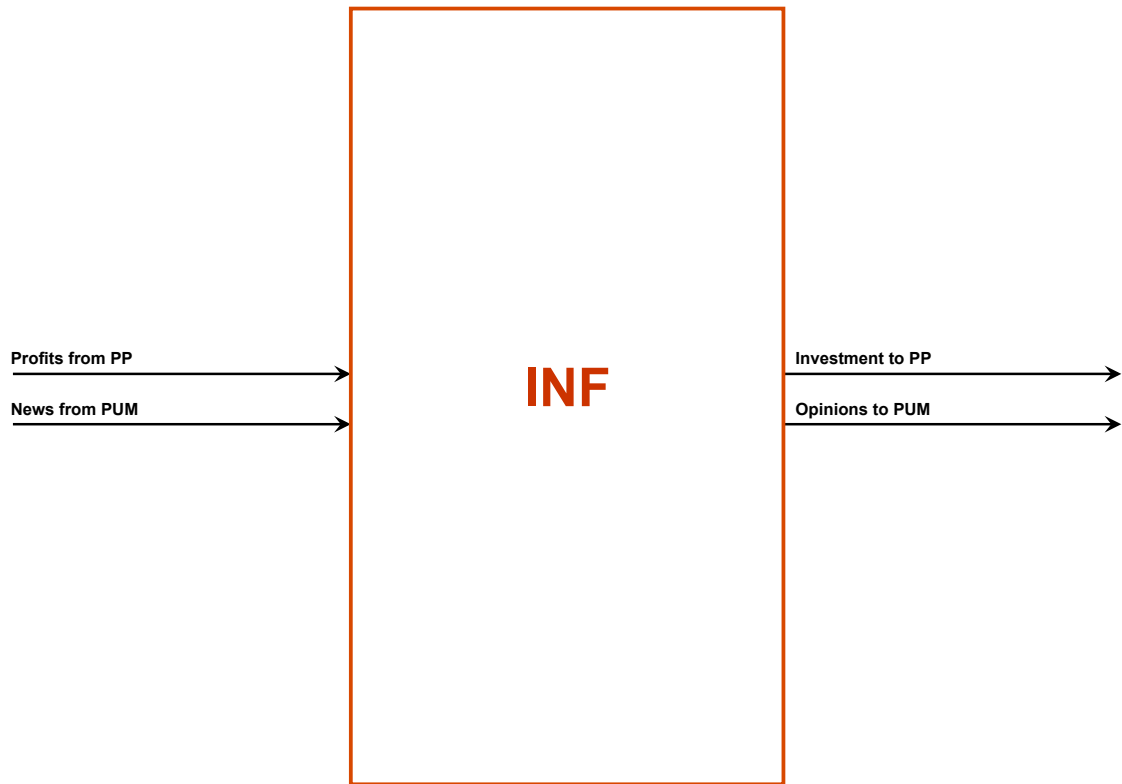


Figure A-4-13: Internal Assets Model for INF

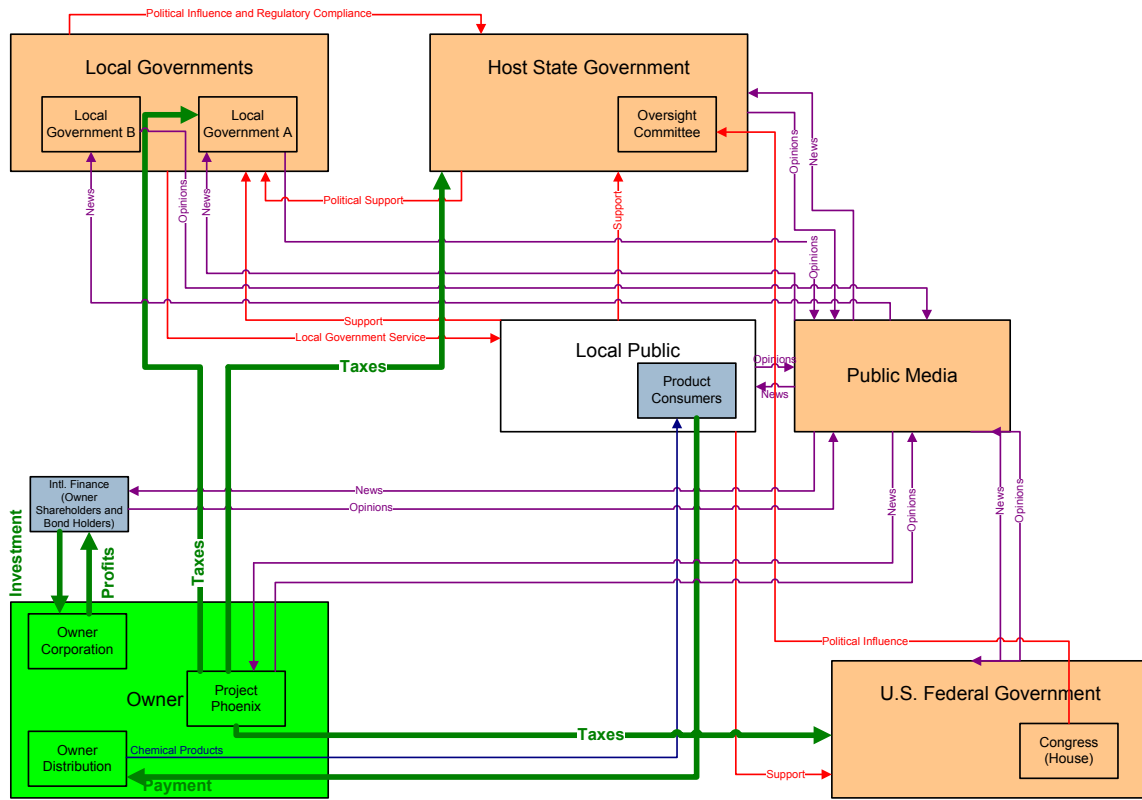


Figure A-4-14: Issue Network 2 of "General Economic Performance"

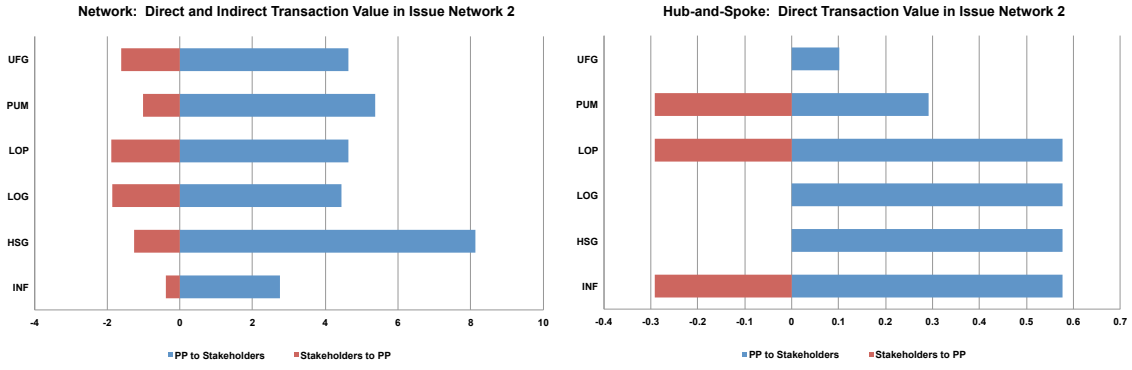


Figure A-4-15: Stakeholder Balance in Issue Network 2

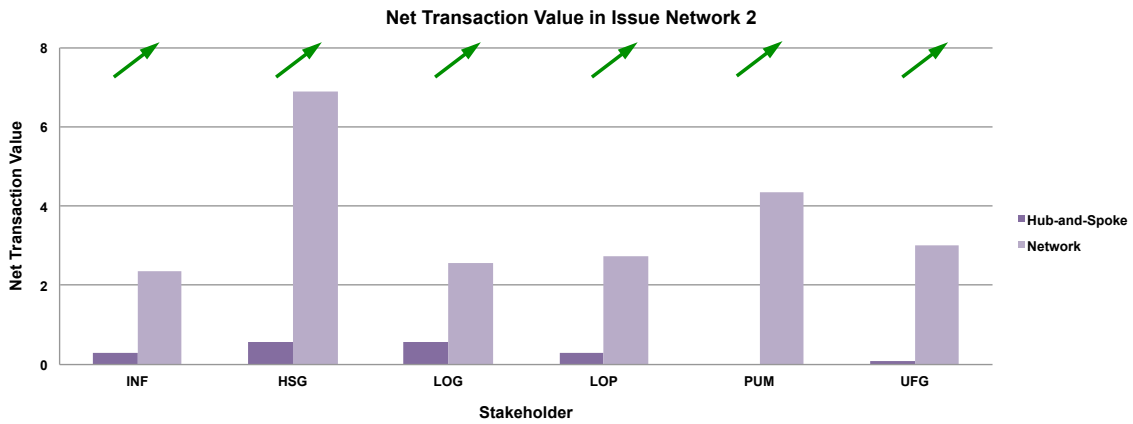


Figure A-4-16: Net Transaction Value in Issue Network 2

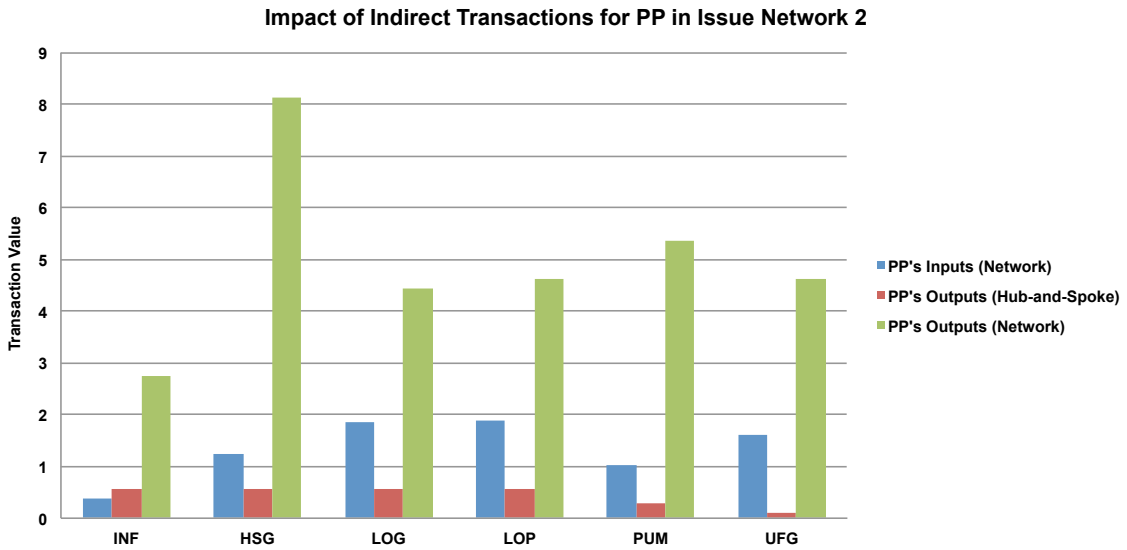


Figure A-4-17: Impact of Indirect Transactions for PP in Issue Network 2

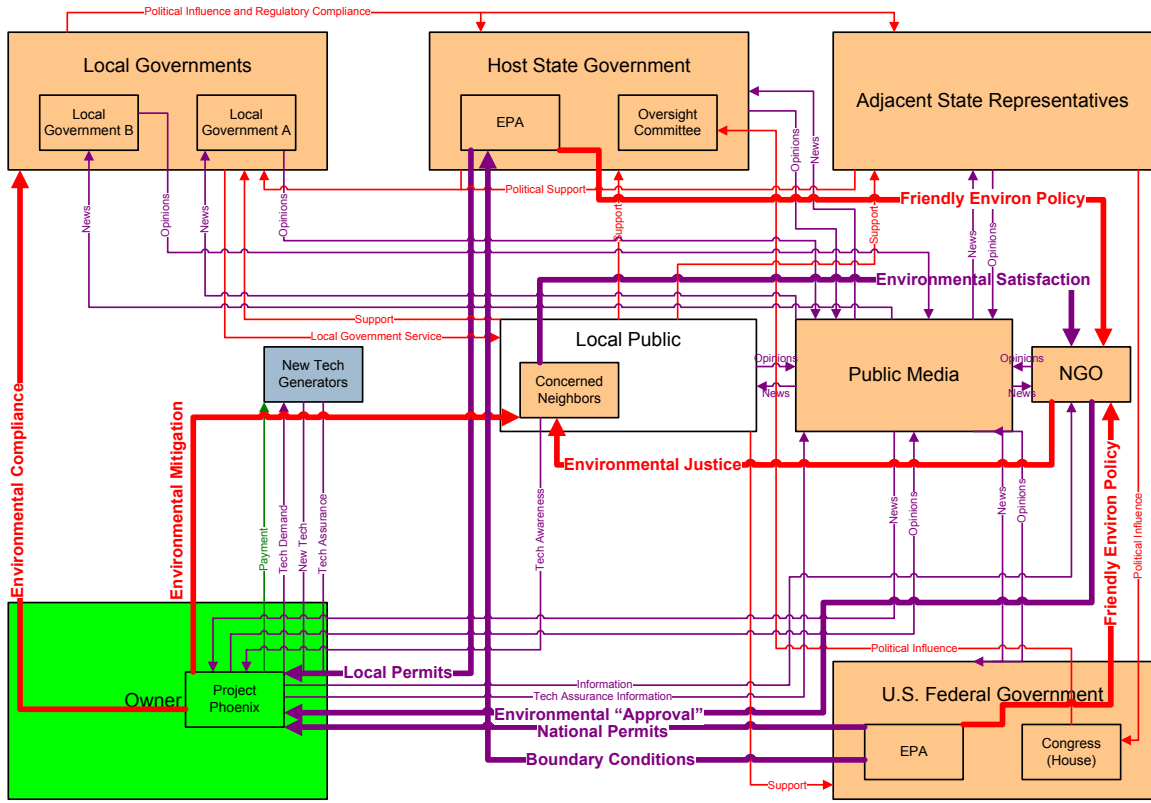


Figure A-4-18: Issue Network 3 of "Local Environmental Protection"

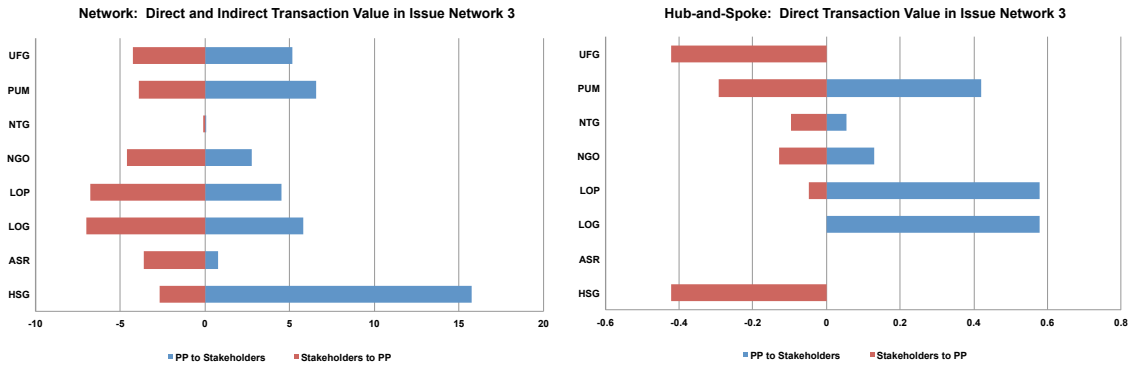


Figure A-4-19: Stakeholder Balance in Issue Network 3

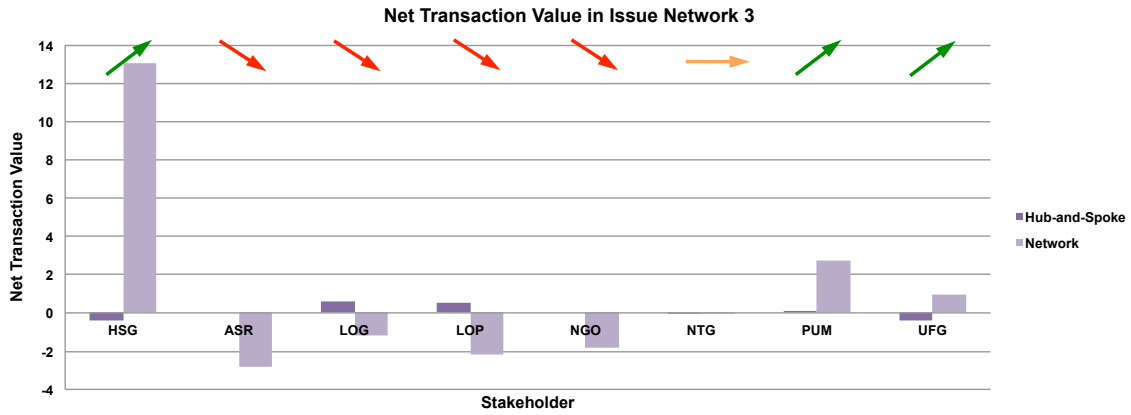


Figure A-4-20: Net Transaction Value in Issue Network 3

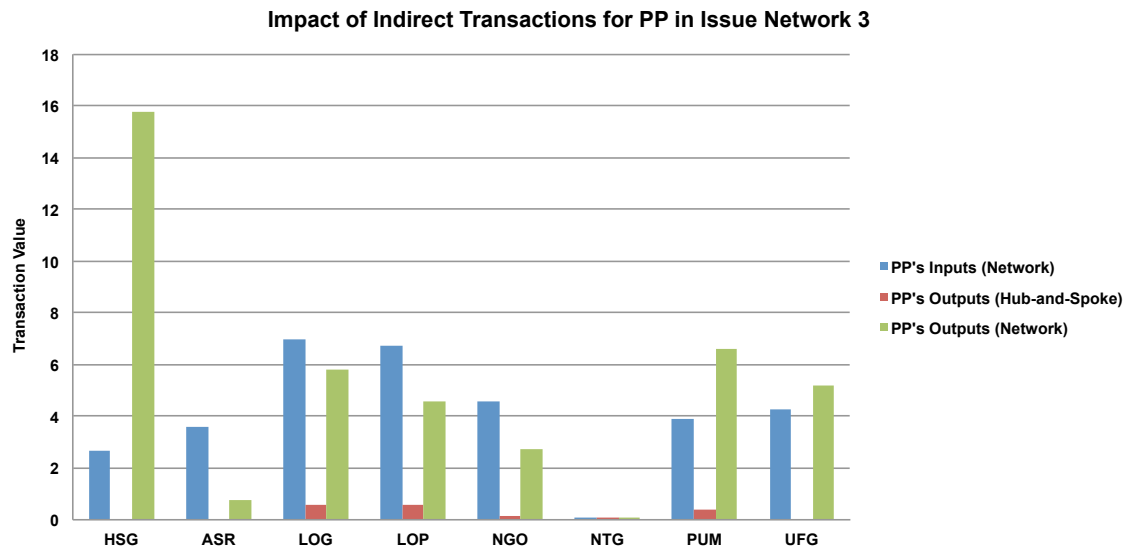


Figure A-4-21: Impacts of Indirect Transactions for PP in Issue Network 3

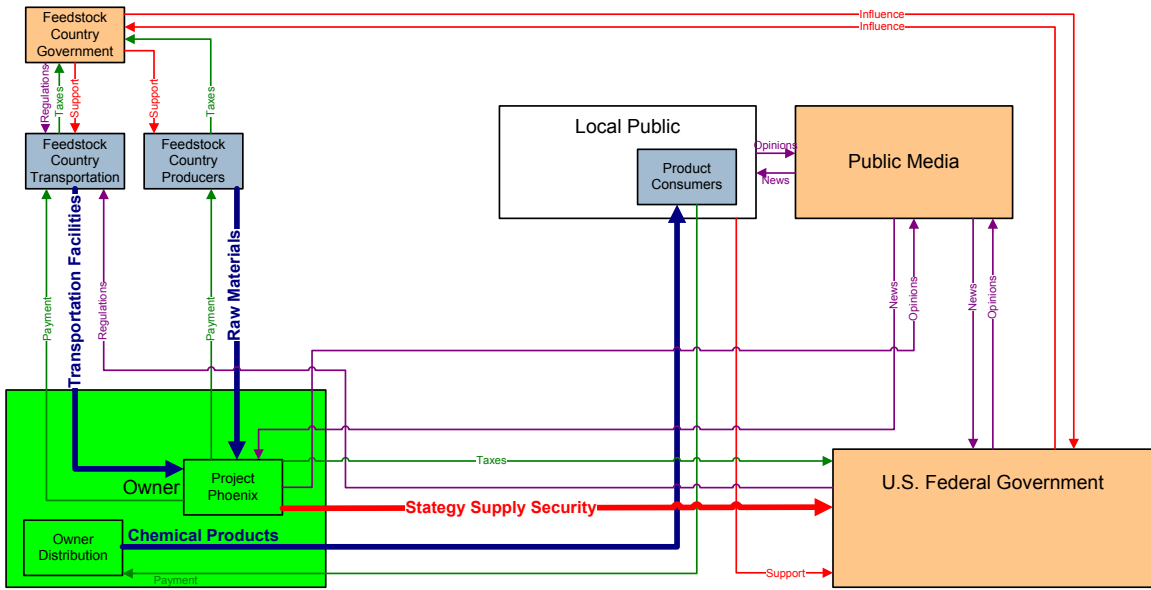


Figure A-4-22: Issue Network 4 of "National Security"

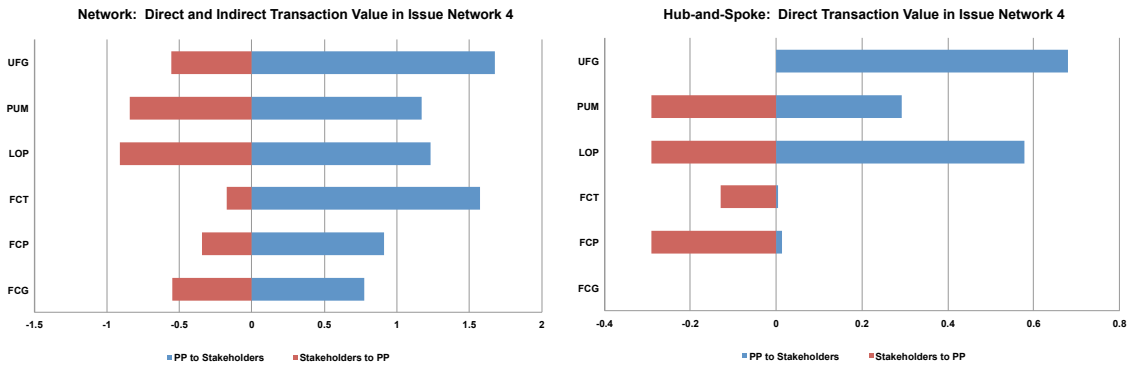


Figure A-4-23: Stakeholder Balance in Issue Network 4

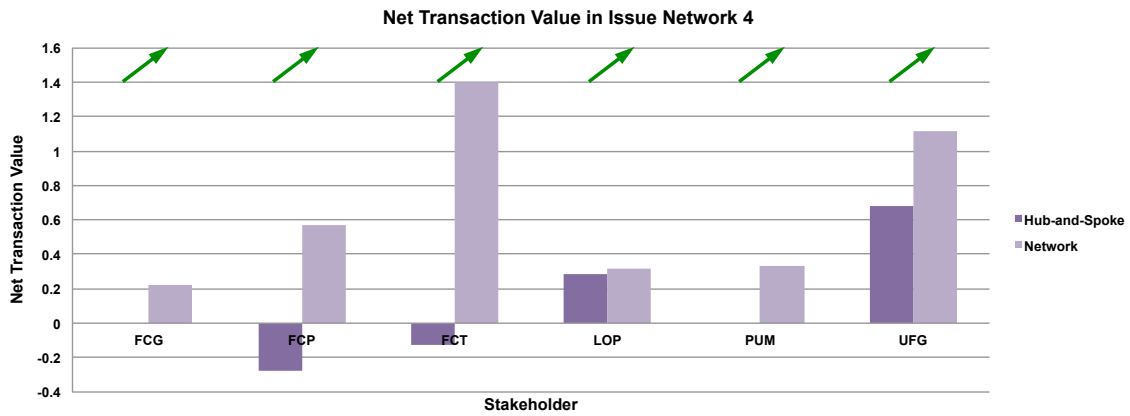


Figure A-4-24: Net Transaction Value in Issue Network 4

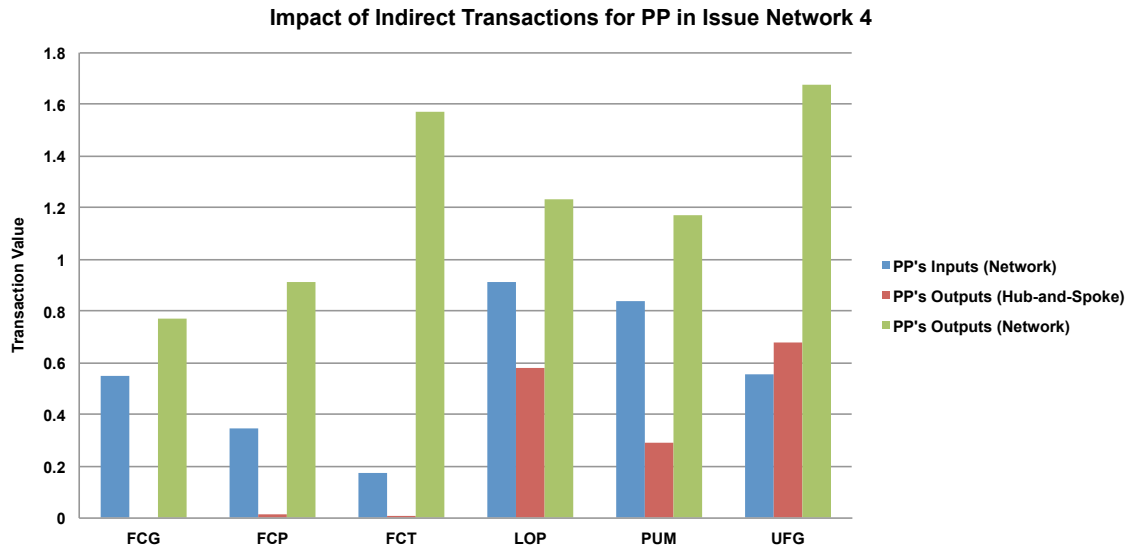


Figure A-4-25: Impact of Indirect Transactions for PP in Issue Network 4

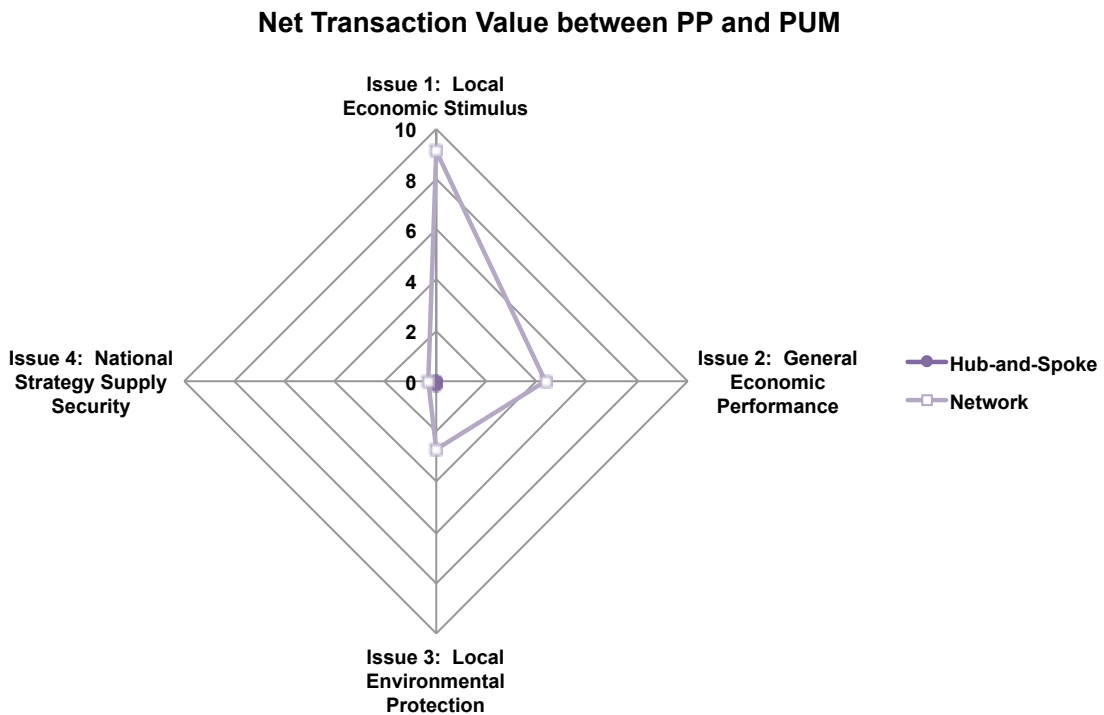


Figure A-4-26: Relationship Balance between PP and PUM across Four Issues

Net Transaction Value between PP and LOG

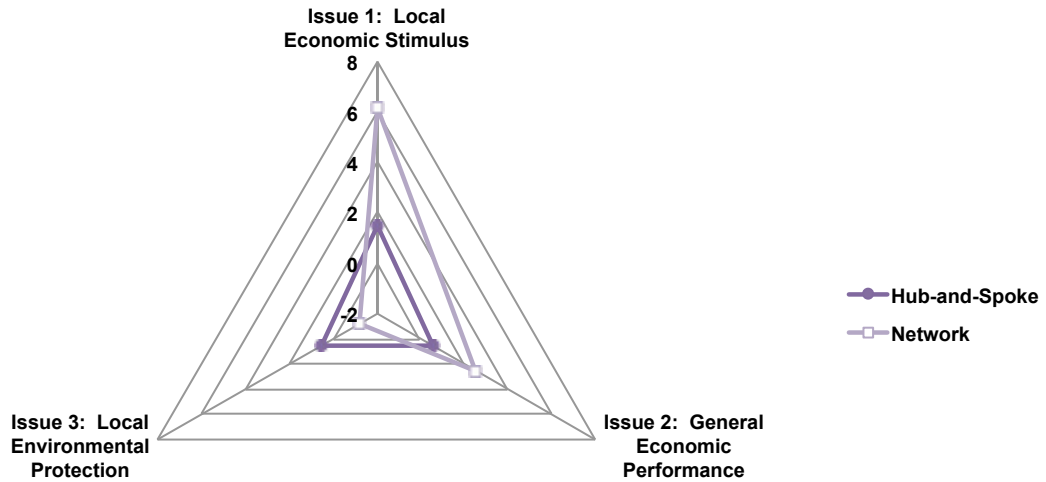


Figure A-4-27: Relationship Balance between PP and LOG across Three Issues

Net Transaction Value between PP and UFG

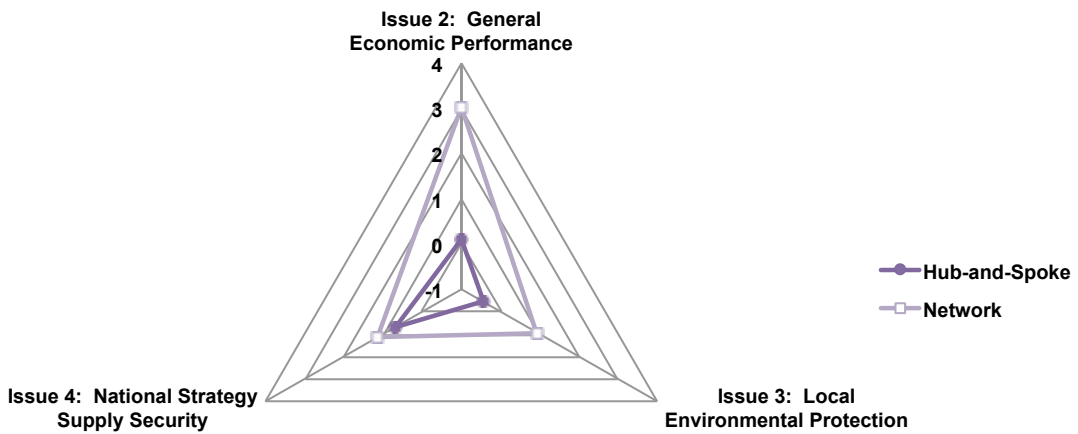
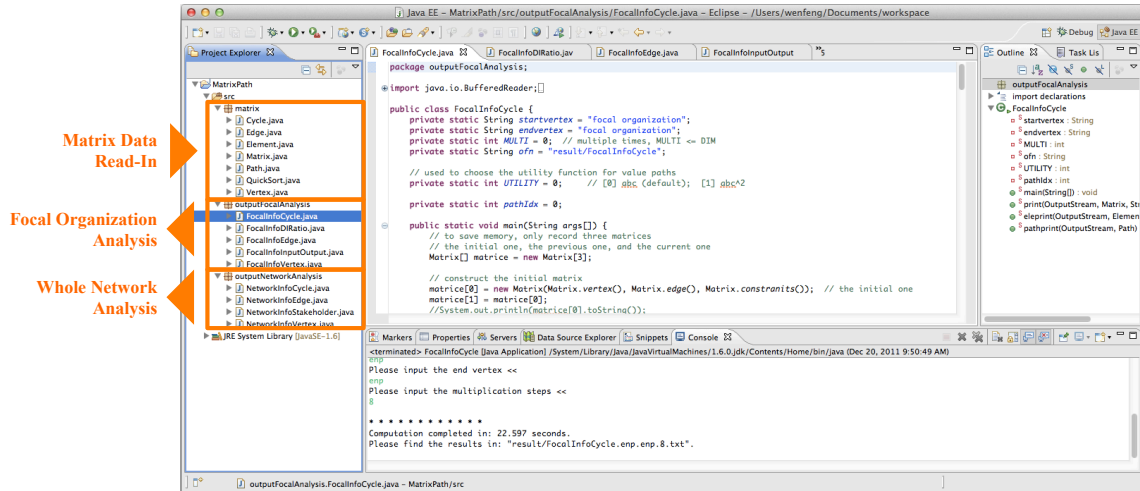


Figure A-4-28: Relationship Balance between PP and UFG across Three Issues

Appendix 5.1 Software Architecture of the DSM Modeling Platform

(This software is in the process of patent application. Please not use or spread without permission.)



Basic Package 1.0

[Matrix Data Read-In]

- Input Files: “input_vertex.dat”, “input_edge.dat” (including edge scores), and “input_constraint.dat” (optional)
- Processing Features:
 - Five Classes of Objects: Matrix, Elements, Path, Vertex, and Edge
 - Three Self-defined Operations: Matrix Multiplication, Element Multiplication, and Element Addition
 - Two Logic Requirements: Simple Path (and Cycle) Check and Internal Asset Constraints (optional)

[Focal Organization Analysis]

- Input Parameters: Utility function (optional), Start vertex, End vertex, and Multiplication steps

- Output Results:
 - “FocalInfoCycle.java”: To identify the Critical Cycles for the focal organization
 - “FocalInfoVertex.java”: To calculate the Weighted Stakeholder Occurrence (WSO)
 - “FocalInfoDIRatio.java”: To calculate the Ratio between WSO_Hub-and-Spoke and WSO_Network
 - “FocalInfoEdge.java”: To calculate the Weighted Value Flow Occurrence (WVFO)
 - “FocalInfoInputOutput.java”: To calculate the Conversion Matrix between the outputs and inputs of the focal organization

[Whole Network Analysis]

- Input Parameters: Multiplication steps
- Output Results:
 - “NetworkInfoCycle.java”: To identify the Critical Cycles within the whole network
 - “NetworkInfoVertex.java”: To calculate the Network Weighted Stakeholder Occurrence (NWSO)
 - “NetworkInfoEdge.java”: To calculate the Network Weighted Value Flow Occurrence (NWVFO)
 - “NetworkInfoStakeholder.java”: To calculate the Relationship Balance Matrix between all the stakeholders

[Additional Features]

<Flexible Utility Function>

Focal Organization Analysis:

- Two basic operation modes are defined to derive different forms for the utility function of value cycles
 - $[v_1 * v_2]$: suitable for “abc”, “abc²”, “(abc)²”, etc.
 - $[v_1 + v_2]$: suitable for “a + b + c”, “a + b + c²”, “(a + b + c)²”, etc.
- Based on Ed’s theory, “abc²” is a good approximation of the optimal solution to maximize the focal organization’s utility
- Compared to “abc”, “abc²” intuitively reflects more interest from the focal organization on its own needs

Whole Network Analysis:

- “abc” is set as the default utility function of value cycles, because all the stakeholders along each value cycle are equally treated from the perspective of the whole network

<Automation of Analysis>

- The latest DSM software directly calculates all the network measurements (i.e., WSO, DI Ratio, WVFO, WOO, WIO; NWSO, NWVFO)
- Computational time and bottleneck (i.e., the maximum multiplication steps, if the matrix is too large for computer’s RAM to handle) are also displayed

Appendix 5.2 Algorithm Memo for the DSM Modeling Platform

(As an Example, Only for the Focal Organization Analysis)

Classes

The main body of the program contains five classes of objects:

- Matrix
- Element
- Path
- Edge
- Vertex

The class of Matrix is used to describe the overall information of the graphic connection. The dimension of the Matrix is $DIM * DIM$, where DIM is the number of total vertices in the graphic. Hence, after k steps of multiplication, $Matrix[i, j]$ is able to maintain all the paths from vertex i to vertex j with path length k .

The class of Element is used to keep the graphic information for each pair of Vertices. Hence, after k steps of multiplication, $Matrix[i, j]$ is actually an instance of Element which contains all paths from vertex i to vertex j with path length equal to k .

The class of Path stands for each path in the graph. It records all the Edge references that construct the path. Note that only Edge references rather than real copy of the Edges are kept in the run time. Hence, we can dramatically reduce the program memory usage and improve the performance.

The classes of Edge and Vertex stand for edge and vertex in the graph respectively. To efficiently process the graph, both edges and vertices are mapped to internal integer ids for internal expression.

Multiplication

1). Matrix Multiplication

In this section, we describe how Matrix multiplication $M3 = M1 * M2$ is designed.

As we know, normal Matrix multiplication can be expressed as follows:

$$M3[i, j] = \sum_{r=1}^{DIM} M1[i, r] * M2[r, j]$$

Here, $M[i, j]$ stands for the Element in row i and column j of M . However, to record all the path information in the matrix and to expand the path length via matrix multiplication, we should redefine the Element *multiplication* and *addition* expressed in the above formula.

2). Element Multiplication

Recall that each Element $M[i, j]$ in the matrix is either a collection of paths or no path at all (expressed as 0). If an Element is 0, which means it cannot contribute to expand paths from any other Element, the multiplication result should also be a zero Element. Otherwise, for $M1[i, r] * M2[r, j]$, where neither of them is zero, the multiplication resulted Element should be a collection of new paths from vertex i to vertex j where each path from $M1[i, r]$ connected with each path from $M1[r, j]$. Path connection strategies will be discussed in the next section.

3). Element Addition

Element Addition $E1 + E2$ is relatively simple. It summarizes all paths from $E1$ and $E2$ together to form a new Element.

The algorithm for Matrix Multiplication, Element Multiplication and Addition is attached in the Appendix 5.3.

Path Connection

In this section, we describe how Paths $P1$ and $P2$ are connected together.

When the last edge from $P1$ is connectable to the first edge from $P2$, we record all edge references from $P1$ and $P2$ in sequence in the resulting new path. Notice here we record edge reference rather than the real edge copy to reduce the memory usage and increase the efficiency.

However, before we really perform the path connection, we need to do two extra condition checks: one is the *redundant loop check*, which will rule out a path having a vertex been accessed more than twice; the other is the *edge constraint check*, which is to check whether the value exchange is doable in the real world.

1). Redundant Loop Check

Before connecting Path $P1$ and Path $P2$ together, we should make sure that the resulted new path does not have redundant loops. In other words, we need to make sure that the path neither has an edge accessed more than once nor an internal vertex (other than the start and end vertex) accessed twice. This requirement is equivalent to the condition that no vertex in the path has input/output degrees greater than 2.

To perform such loop check, we maintain a bitmap style loop check array LCA for each path to record the corresponding input and output degrees of each vertex in that path. If the path has an edge starting from or ending with node i , we will increase i 's degree by one. If any vertex's degree in the path is greater than 2, this path is defined to have redundant loops and ruled out.

An important advantage of our loop check method is that it avoids a pass of accesses to the entire new path so as to recalculate the new LCA , because the new LCA can be deducted by directly adding $P1$'s LCA and $P2$'s LCA together when $P1$ and $P2$ are connected together. More specifically, $LCA[i] = LCA_{p_1}[i] + LCA_{p_2}[i]$, where $i \in [0, DIM)$ stands for Vertex i in the path. If $LCA[i] > 2$, the current considering path would be dropped directly without further calculation. In this way, we can efficiently check redundant loop without any unnecessary calculation.

2). Edge Constraint Check

Another important issue during path connection is edge constraint check. Edge constraint check is to check whether the value exchange makes sense in the real world. Each time two paths $P1$ and $P2$ are to be connected, the last edge from $P1$ is checked against the first edge from $P2$ to make sure that they are connectable. To fulfill this, we maintain in the program a hash map to record all the connectable information. If the paths (edges) are not connectable, the new path is dropped.

Appendix 5.3 Example Java Code for the DSM Modeling Platform

(As an Example, Only for the Focal Organization Analysis)

```
// * * * * *
```

Matrix Input

```
// * * * * *
```

```
/* Matrix.java
 * Initial Matrix Constructor
 * Input:
 *   String fnode: Node Input File
 *   String fedge: Edge Input File
 *   String fcons: Constraint Input File
 */
Matrix(String fnode, String fedge, String fcons) {

    // Read in the node information
    try {
        BufferedReader bufRead = new BufferedReader(new FileReader(fnode));
        String line; int count = 0;

        // Read the first line
        line = bufRead.readLine(); count++;

        // Read through the file
        while(line != null) {
            Vertex n = new Vertex(line); // construct a new node
            nodemapi2n.put(new Integer(n.intval), n);
            nodemaps2n.put(n.name, n);
            line = bufRead.readLine(); count++;
        }
        bufRead.close();
        DIM = count-1;
        System.out.println("Totally " + DIM + " nodes constructed.");
    } catch (IOException e) { e.printStackTrace(); }
}
```

```

// Read in the Edge information
matrix = new Element[DIM*DIM];
try{
    BufferedReader bufRead = new BufferedReader(new FileReader(fedge));
    String line; int count = 0;

    // Read the first edge
    line = bufRead.readLine(); count++;

    // Read through the file
    while(line != null) {
        Edge e = parseEdge(line);
        if (getElement(e.start, e.end) == null) {
            setElement(e.start, e.end, new Element(e));
        }
        else getElement(e.start, e.end).addPath(e);
        edgemaps2e.put(e.name, e);
        edgemapi2e.put(e.id, e);

        line = bufRead.readLine(); count++;
    }
    bufRead.close();
}catch(IOException e) { e.printStackTrace(); }

// Read in the constraints
try{
    if (fcons == null) return;
    BufferedReader bufRead = new BufferedReader(new FileReader(fcons));
    String line; int count = 0;

    // Read the first edge
    line = bufRead.readLine(); count++;

    // Read through the file
    while(line != null) {
        parseConstraint(line);
        line = bufRead.readLine(); count++;
    }
    bufRead.close();
}catch(FileNotFoundException e) {

```

```

    System.out.println("no constraint file :-)");
    connection = null; // no constraints
} catch (IOException e) { e.printStackTrace(); }
}

```

```
// * * * * *
```

Main Algorithm

```
// * * * * *
```

```

/* Matrix.java
 * Matrix Multiplication
 * Input:
 *   Matrix M1: the left multiplier
 *   Matrix M2: the right multiplier
 * Output:
 *   Matrix: the result matrix
 */
public static Matrix multi(Matrix M1, Matrix M2) {
    Matrix M = new Matrix();
    for(int k=0; k<DIM; k++) { // M1-row
        for(int c=0; c<DIM; c++) { // M2-column
            Element sum = new Element();
            for (int r=0; r<DIM; r++) { // M2-row, M1-column
                Element e = Element.multi(M1.getElement(k, r), M2.getElement(r, c));
                if(e != null)
                    sum.plus(e);
            }
            if (sum.pathNumber() == 0) sum = null;
            M.setElement(k, c, sum);
        }
    }
    return M;
}

```

```

/* Element.java
 * Element Multiplication
 * Input:
 *     Element e1: the left multiplier
 *     Element e2: the right multiplier
 * Output:
 *     Element: the result element
 */
public static Element multi(Element e1, Element e2) {
    if(e1 == null || e2 == null) { return null; }
    Element element = new Element();
    for(int i=0; i<e1.pathNumber(); i++) {
        for(int j=0; j<e2.pathNumber(); j++) {
            Path p = Path.connect(e1.getPath(i), e2.getPath(j));
            if(p != null) element.paths.addElement(p);
        }
    }
    if (element.pathNumber() == 0) return null;
    return element;
}

```

```

/* Element.java
 * Element Plus
 * Input:
 *     Element e: the element to be added
 */
public void plus(Element e) {
    for(int i=0; i<e.pathNumber(); i++)
        paths.addElement(e.paths.get(i));
}

```

```

/* Path.java
 * Path Connection + Redundant Loop Check
 * Input:
 *     Path p1: the first path to be connected

```

```

*      Path p2: the second path to be connected
* Output:
*      Path: the result connected path
*/
public static Path connect(Path p1, Path p2) {
    // whether p1.last matchable with p2.first
    if(!p1.connectable(p2)) return null;
    short[] lc = new short[Matrix.DIM];
    for(int i=0; i<Matrix.DIM; i++) {
        lc[i] = (short)(p1.loopcheck[i] + p2.loopcheck[i]);
        // check whether having multiple loops
        if(lc[i] > DEGREE) return null;
    }

    // no multiple loop, connect the path together
    Path p = new Path(p1, p2, lc);
    return p;
}

/* Path.java
* Constraint Check, whether the first edge of Path p satisfies the constraint with the
last edge of the current path
* Input:
*      Path p: the path to be connected
*/
private boolean connectable(Path p) {
    if (Matrix.connection == null) return true;

    Edge last = path.lastElement();
    Vector<Edge> connect = Matrix.connection.get(last);
    if (connect == null) return true;

    Edge first = p.path.firstElement();
    if (connect.contains(first)) return true;
    return false;
}

```

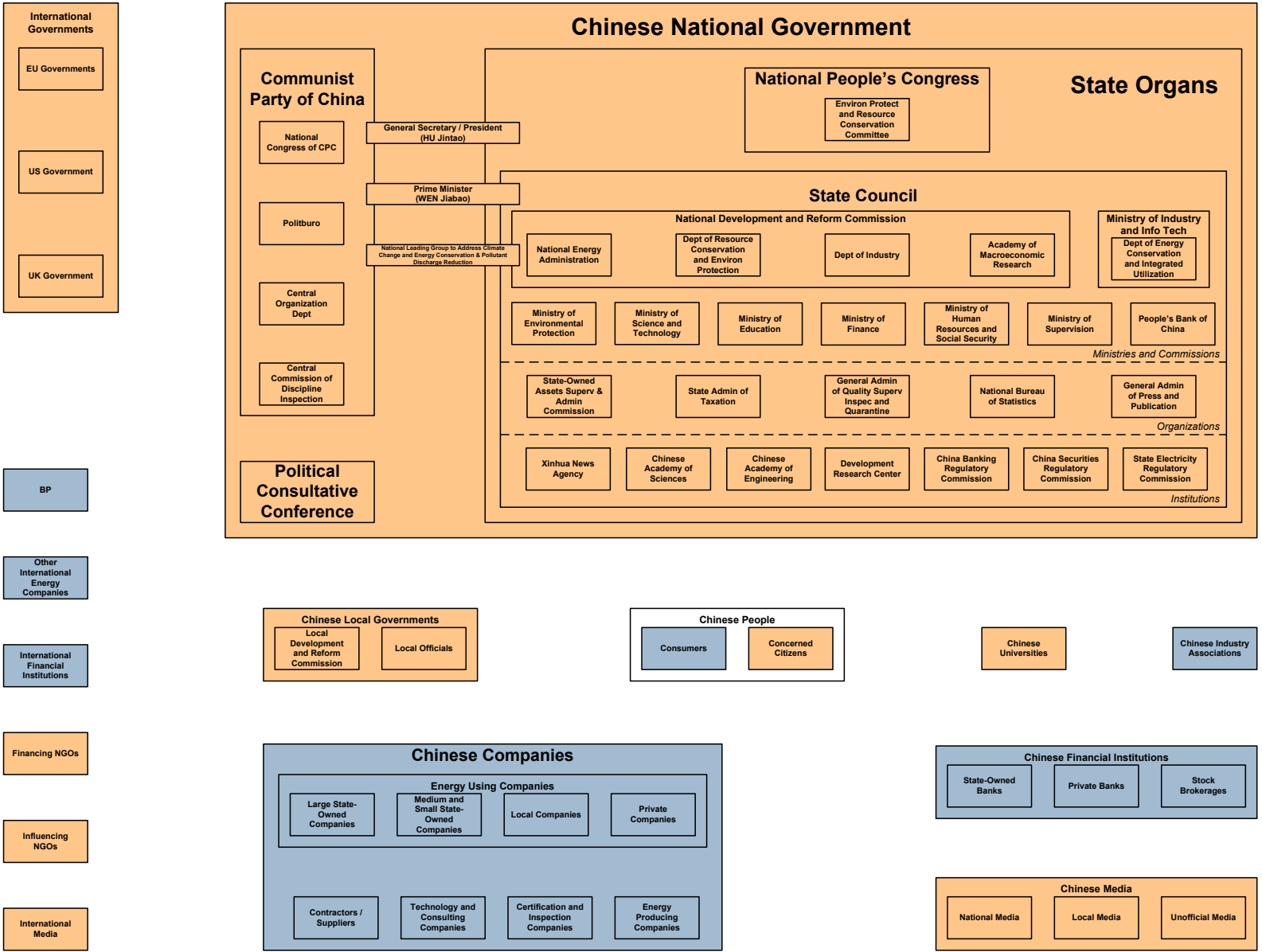


Figure A-6-1: Stakeholder Map for Level Three Model (76 Stakeholders)

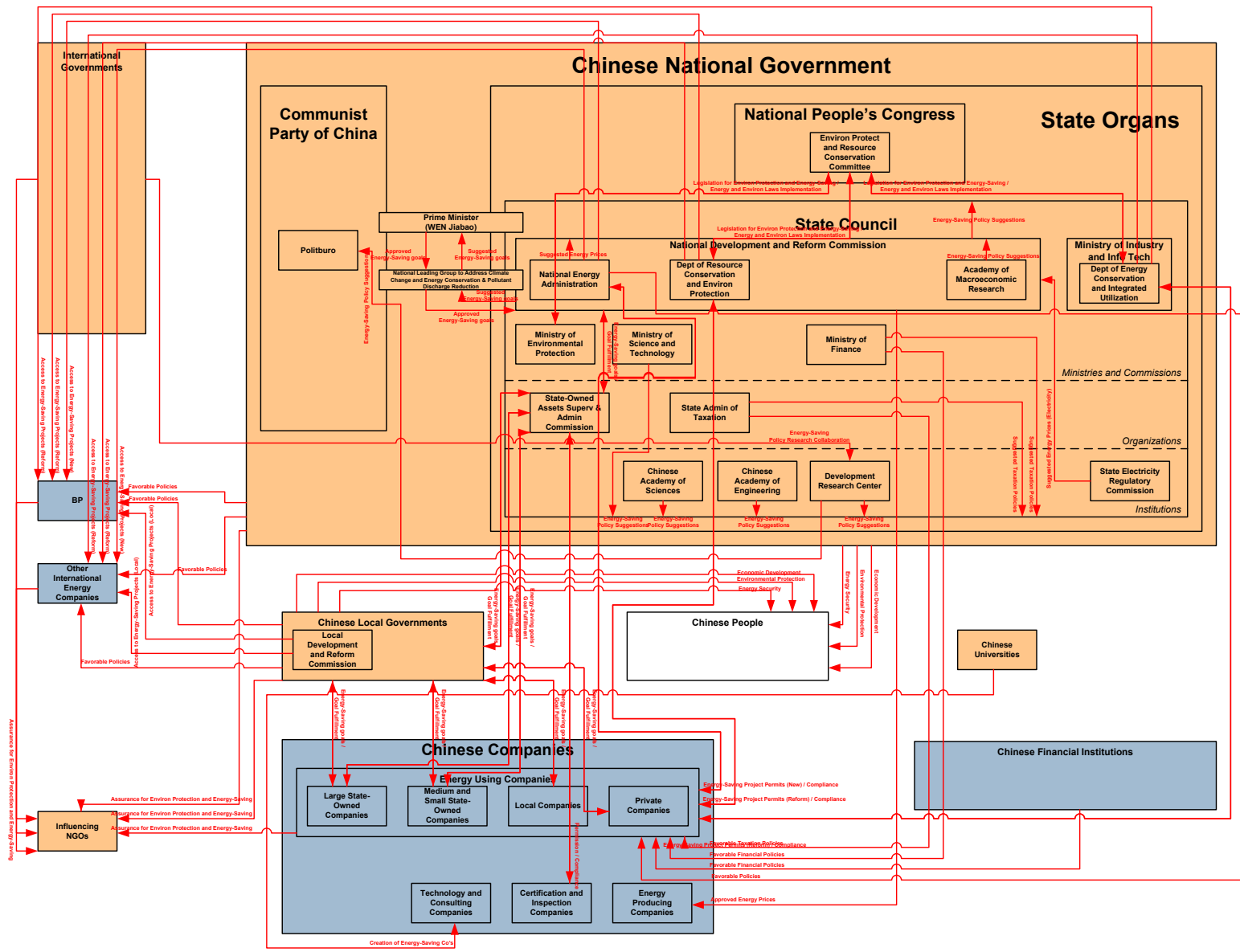


Figure A-6-3: Stakeholder Map for Level Three Model (Political Flows Part 2)

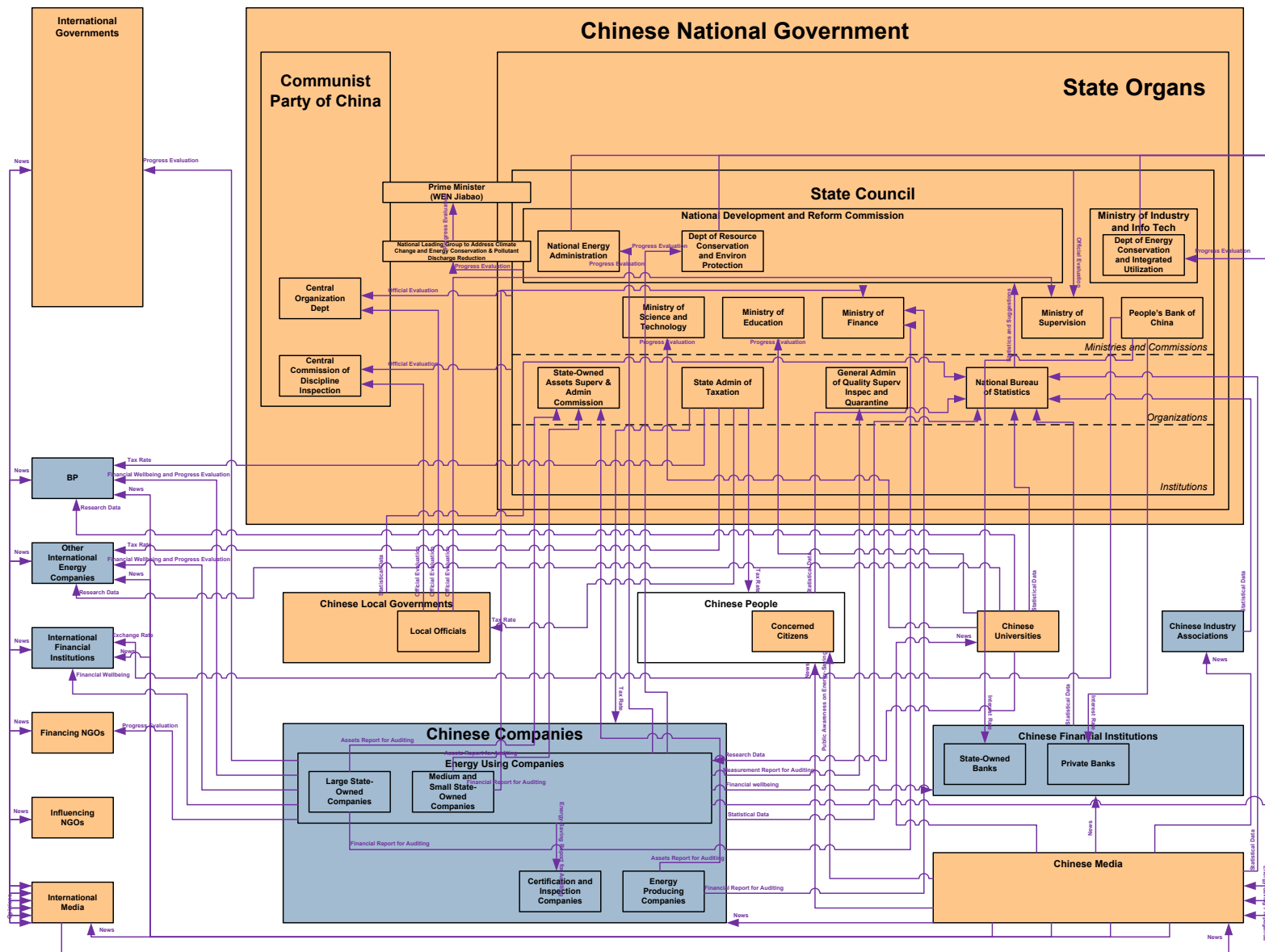


Figure A-6-4: Stakeholder Map for Level Three Model (Information Flows)

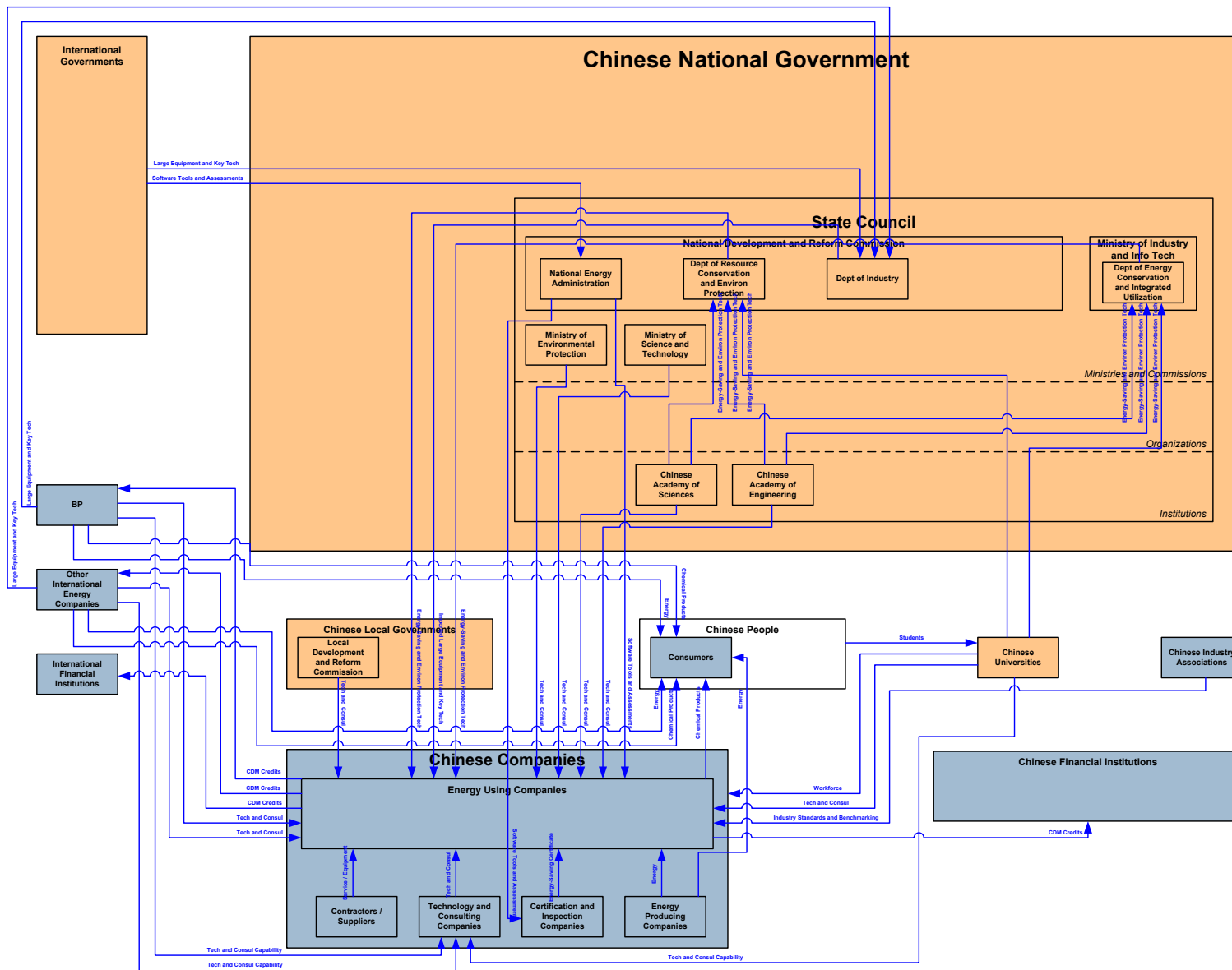


Figure A-6-5: Stakeholder Map for Level Three Model (Goods/Service Flows)

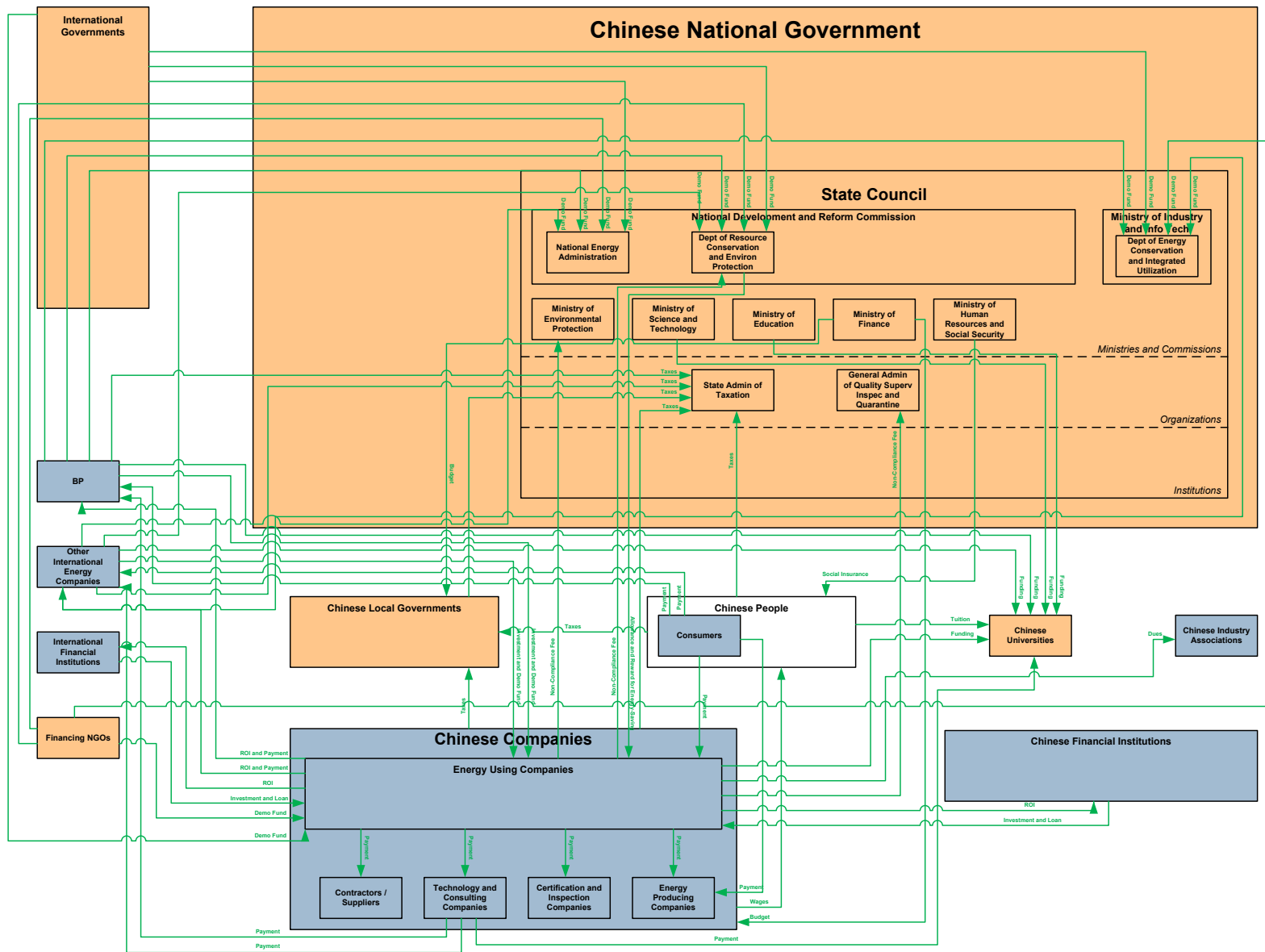


Figure A-6-6: Stakeholder Map for Level Three Model (Financial Flows)