

# Strategic Decisions in Complex Stakeholder Environments: A Theory of Generalized Exchange

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**Abstract:** The authors develop a methodology to compare the firm's knowledge of its networked environment with the priority of its needs. This enables managers to make explicit decisions about the firm's needs, and the feasibility of satisfying them with the firm's production function. A scalable mathematical model of indirect transactions has been built on a foundation of a theory of generalized exchange. Using a multinational resource extraction project as an example, we show how this methodology can be used to prioritize the outputs of the firm, relative to its needs and its strategic environment. This work enables managers to perform an analysis of the firm's stakeholders to determine the relative priority of stakeholder needs, according to the stakeholder's importance to the firm, prior to the translation of needs into requirements.

**Keywords:** Corporate Strategy, Generalized Exchange, Social Networks, Computational Organization Theory

**EMJ Focus Areas:** Economics of Engineering; Program & Project Management; Quantitative Methods & Models; Strategic Management

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Choosing a business strategy requires managers to make explicit choices about the relative value of different actors in the market; however, these decisions also make implicit choices about the relative worth of different inputs to the firm, inputs which clients and suppliers provide. These two problems are causally linked, but rarely treated together.

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 (Smith, 1985). Where the firm deals directly with clients and few intermediaries, it is easy to watch how one's priorities result in outcomes; however, when clients and suppliers are diverse, and the firm interacts indirectly with them, the management of priorities becomes more difficult (Roloff, 2008), because it is complicated to track which choices cause which results. This has led to concern that broad and unmeasurable corporate objectives may enable self-serving behavior by managers (Orts, 1992) or promote vague goal setting (Pleon, 2004). Situations like these arise in a multitude of industries, from engineering spacecraft for NASA (Cameron, 2008; Cameron, 2010) to multinational commodity ventures.

The general objective of this article is to develop a theory of indirect transactions, so as to more directly connect business strategy with implementation decisions. Understanding indirect transactions will enable managers to make more explicit decisions about who benefits in a network of actors and will connect the problem of producing outputs to the problem of prioritizing the desired inputs to the firm.

Stakeholder theory offers a strong starting point for this analysis. Work following Freeman's first conceptualization (Freeman, 1984) has focused on the definition and prioritization of actors related to the firm in a variety of contexts. Mitchell (1997) offered a chronology of stakeholder definitions, ranging from actors necessary for the survival of the firm, to actors in the environment which could be affected by the firm's actions. Our approach is decidedly instrumental, in that we seek to connect stakeholder outcomes to actions of the firm. Previously in Cameron (2008), we outlined how the construction of a network can operationalize stakeholder definitions. By requiring that stakeholders provide or enable important inputs to the firm, we established completeness criteria for the set of relevant stakeholders. As a corollary to the theory developed in this article, we will prioritize the stakeholders, using emergent properties of the network.

Mitchell (Mitchell, 1992; Agle, Mitchell, and Sonnenfeld, 1999) advanced an influential framework in the instrumental tradition (Donaldson and Preston, 1995) for quantitatively valuing stakeholders along three dimensions. We build Mitchell's stakeholder quantification out in an important dimension: rather than parameterizing the stakeholder, we parameterize the relationship to the stakeholder, which can be broken out into separate transactions – some important, some not. While our characterization does not capture the same richness in the time/urgency or legitimacy dimensions as Mitchell, we ground the understanding of power in economic exchange conditions.

The economic foundations for this work lie in the theory of General Equilibrium in microeconomics, originally developed by Arrow, Debreu, and McKenzie (1954). In this framework exchange prices depend on quantity demanded, location, and timing. Relaxations include information asymmetries (Akerlof, 1970) and uncertainty in the future state of the system (Magill and Quinzii, 2009).

The branch of economics that has dealt with the relaxation for indirect transactions is principal – agent theory. In an agent problem, the principal transfers risk across a contract to an agent. The literature explores the structuring of contracts to reduce costs (Prendergast, 1999), choose the right agents (Nalebuff and Stiglitz, 1983), and prevent moral hazard (lack of effort or withholding of information by the agent) (Arrow, 1963). The majority of the literature focuses on principal-agent pairs; whereas, we will use the concept recursively, such that actor 1 can be both the principal for actor 2 and the agent of actor 3. Said otherwise, we will explicitly create cycles in the graph of actors. As such, the contracts represented in this model will be significantly simpler than most studied under principal-agent theory. Where these contracts represent non-monetary exchanges, utility theory has been used to record the preferences of actors. For simplicity, we also consider these actors internally consistent – we ignore the

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heterogeneities and principal-agent relationships at work *within* each stakeholder (Cyert and March, 1992; Frederick, 1992).

Exchanges and social networks have been studied in sociology, anthropology, and management. Our interest is framed under “network-generalized” exchange (Yamagishi and Cook, 1993; Willer, 1999), to indicate that players act individually rather than pooling resources in groups. The focus of study in sociology is on the development of trust (Ekeh, 1973), free-riding (Hardin, 1968; Albanese and Van Fleet, 1985), and non-monetary exchanges (such as inter-tribal marriage (Homans and Schneider, 1955), with a view to explaining group behavior. We will study a specific type of exchange explored in this literature, namely cycles, and will focus on creating advantage for one actor, rather than overall group behavior. Rowley (1997) was one of the first to suggest the potential for using social networks to capture the relevant dynamics *between* stakeholders, in addition to the *direct* relationships between stakeholders and the firm. Subsequent work has produced quantitative studies of stakeholder networks using social network analysis (Rowley, Behrens, and Krackhardt, 2000; Dyer and Nobeoka, 2000), based on the presumption that relational data between stakeholders suffices, as the network structure determines behavior (Faust and Wasserman, 1995); however, our interest lies in prioritizing relationships among players, thus network metrics such as centrality or stability (Lim, 2010; Jackson, 2003) are insufficiently detailed, in that they assume all edges represent relationships of equal strength. We hypothesize that graph cycles will enable us to represent the essential qualities of the network structure and exchange, and further, that more detailed models of relationships will reveal testable predictions related to the prioritization of stakeholders. The astute reader will note that we are tending toward developing a control theory of economic exchange conditions; however, rather than representing actors using a detailed systems dynamics model, we will make enough simplifications in the utility and production functions of the actors to generate explicitly solvable static systems.

From an engineering management perspective, there is a significant literature base in the prioritization of needs and their translation into requirements, such as Quality Function Deployment (Kauffman, 2000) and the goals literature (Johnson, 2001); however, available methods for balancing between different stakeholders is limited to market segment sizing, simple averaging (Karlsen, 2002) or panel judgment (Botta, 2007), which can be inappropriate for complex projects with non-monetary exchanges. Further, these existing methods consider stakeholders as direct relationships (Cheng, 2007; Damian, 2007), but have not incorporated the network effects resulting from indirect relationships. Where requirements prioritization methods consider stakeholder

networks (Penserini, 2006), they do so qualitatively by illustrating the network, but not computing the quantitative relationships. This work could be used to inform this needs prioritization (Botta, 2007), prior to requirements translation. Further, where large projects are managed using a mix of quantitative and qualitative metrics, as with the balanced scorecard approach (Kirchoff, 2001), the explicit construction of a network of stakeholders can define the full spectrum of outcomes (Kaplan, 2001), thus ensuring completeness (as was an early criticism of the limited “four perspectives” of balanced scorecard).

Given this grounding, we proceed from here to develop our exchange model. This article is organized in four parts. We first develop the logic for indirect exchange, then formalize it in a mathematical model. A network example of a joint venture in a foreign country is developed, and finally, we apply the model to set the relative priority of the firm’s outputs to reflect its prioritization of actors according to the importance of the inputs to the firm which they provide.

### Exchange Model

The problem of prioritizing multiple needs of a particular client has been well solved. Among other methods, Multi-Attribute Utility Theory (MAUT) enables a firm to define a set of functions that establish the relative importance of different needs (Thurston, 1989).

The problem, however, of prioritizing among multiple transactions with multiple clients has not been well solved. One solution is to extend MAUT by defining weights for the importance of different stakeholders, to arrive at a weighted set of needs among many stakeholders; however, no clear consensus has emerged on a methodology for determining the weighting between stakeholders (Keeney and Raiffa, 1993). We explore a method for determining these weights, with the end goal of determining the appropriate allocation of the firm’s resources to multiple outputs. We break this problem into three parts:

- Prioritizing stakeholders who provide a single good to the firm
- Valuing non-monetary transactions
- Tracing indirect transactions with stakeholders

Prioritizing clients is not difficult if they only return a single revenue stream to the firm. In this case, we can prioritize clients by the returns. The simplest case is prioritizing clients by profit, where the relative priority of the client is defined by the profit returned. In this case, we assume that all needs must be met in order for the client to provide the return flow, although we will relax this assumption later. The transaction problem is very well solved, both in terms of the prices at which trade occurs, as

**Exhibit 1.** Prioritization of Outputs in Direct Interactions with Two Clients



well as other attributes of the transaction, such as information asymmetries and transaction costs.

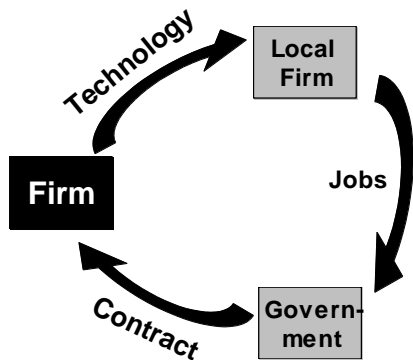
The important underlying principle here is that stakeholders should be prioritized by the value they provide to the firm. The idea of valuing clients by the inputs they provide is not a new one. Locke (2003) calls this strategy “Encompassing” Corporate Citizenship, in that the firm takes multiple beneficiaries into account (rather than simply the stockholders), but does so out of the belief that this is in the long term interests of the firm, rather than out of philanthropy. While this principle is immediately obvious for direct, monetized transactions, it is extensible to a much more general case.

We can easily generalize the transaction to an exchange of goods and services for goods and services, as shown in Exhibit 1. Although we have lost the ability to compare across the inputs to the firm using a common metric (dollars in the previous case), we can easily apply the same MAUT used for the needs of a single stakeholder to establish the hierarchy of the firm’s inputs.

This simple framing of the problem enables us to examine a more complex version of the problem, where transactions are no longer direct, two party exchanges, but where transactions involve indirect flows of goods and services. Indirect flows are defined as those transactions with one or more intermediaries between the firm and the end beneficiary. Note that in an indirect transaction, we no longer require that the price paid for a benefit come from the party which receives the benefit.

This indirect behavior arises in many transactions – for example, in securing foreign contracts with the help of a local partner. The firm provides technology to the local partner, the local partner provides employment to the government, and the government provides a contract to the firm, as illustrated in Exhibit 2.

**Exhibit 2.** Example of an Indirect Transaction



Broadening the example to include multiple transactions, we can see that the network quickly becomes complex. Despite the fact that the relationship between the firm’s outputs and its resulting inputs is no longer direct, it is still possible to prioritize the firm’s outputs. This is accomplished by tracing backward from the firm’s important inputs to the stakeholders who provide them, and then further to the outputs of the firm satisfying the needs of those important stakeholders. Where there are multiple paths to a given input, it becomes necessary to bring in information from the first two subproblems to prioritize among these paths.

Having expressed the foundational concepts and logic for this endeavor, we now formalize these ideas as a mathematical model.

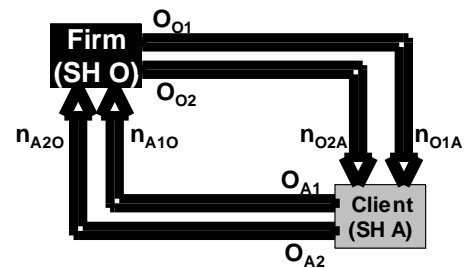
**Network Model**

The goal of this section is to specify a mathematical framework for determining how to prioritize the outputs of the firm. Specifically, it is our stated desire to produce analysis that can be computed simply, with a minimum of complexity. We sought several behaviors from this model – namely:

- 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 path can be computed independently of the other paths through the network.
- Cost Benefit Tests: Analysis should indicate which loops do not provide the minimum return.

We propose the following mathematical model for treating this network exchange problem. Each node (stakeholder) is modeled using the four equations, illustrated here for a two input problem in Exhibit 3. In this sense, we are attempting to create bridge between Donaldson’s input-output model with the stakeholder model (Donaldson and Preston 1995).

**Exhibit 3.** Notation for Single Stakeholder Problem



**Utility**

We apply a non-linear model of the organization, linear utility at each of the stakeholders. The non-linearity of the organization’s preferences is set by the exponent  $\nabla$ , ranging [0,1]. Non-linear utility for each stakeholder is avoided as it couples the network together – we will show that linear utility functions ( $\nabla=1$ ) for stakeholders are sufficient to produce diminishing marginal rates of substitution. We define Utility ( $U$ ) as 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 Output 1 of Stakeholder O.

$$U_{in} \mid n_1 I_1^\zeta \ 2 \ n_2 I_2^\zeta \tag{1}$$

**Resources Received**

Resources are derived from utility received. We express these resources as a function of utility to convey that the material and information outputs produced by the firm are sourced from the inputs it receives. The constant  $p$  captures the propensity of the stakeholder to convert its received utility into outputs. In this model, we refrain from the dynamic implications of the accrual of utility stocks, but instead use  $p$  to represent the propensity to convert received utility to outlaid resources, as might be useful for differentiating among for-profit and non-for-profit stakeholders.

$$R \mid pU_{out} \tag{2}$$

### Resource Utilization

Outputs are constrained by available resources. We explore two types of resource models. In material cases, outputs ( $O_1$  and  $O_2$ ) compete for resources ( $R$ ) (Equation 3a). In select information cases, outputs do not compete for resources (Equation 3b) – equivalently, the marginal cost of producing or changing additional units is zero.

$$R \mid O_1 \geq O_2 \quad (3a \ \& \ 3b)$$

$$R \mid O_1 \ \& \ R \mid O_2$$

### Satisfaction

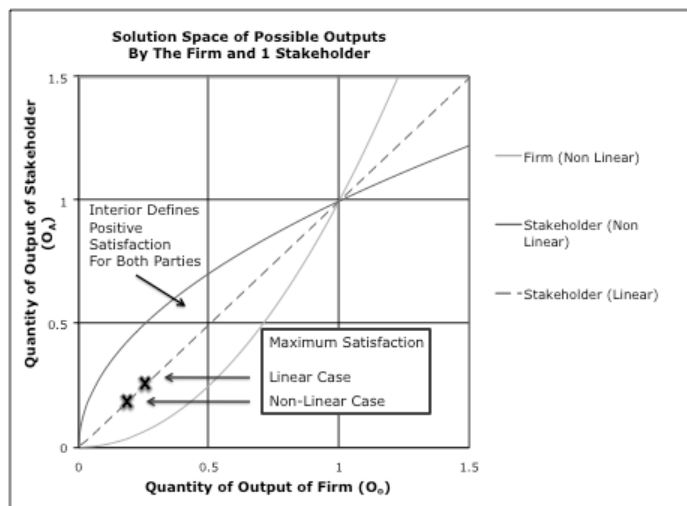
We propose satisfaction ( $S$ ), the generalization of profit, as the equilibrium condition. Stakeholders must profit from the utility transaction in order to engage in it; therefore, we constrain  $S$  to be non-negative.

$$S \mid U_{in} \geq U_{out} \geq 0 \quad (4)$$

In order to demonstrate the solution method for this problem, we solve for the outputs in the following exchange. 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 Organization and Stakeholder A) and six constraints (Equations 1-3a) in four variables ( $O_{O1}$ ,  $O_{O2}$ ,  $O_{A1}$ ,  $O_{A2}$ ) with seven constants ( $n_{A1O}$ ,  $n_{A2O}$ ,  $n_{O1A}$ ,  $n_{O2A}$ ,  $P_O$ ,  $P_A$ ,  $\nabla$ ). Optimizing for the maximum combined satisfaction of the two players is underdetermined and heavily coupled.

**Exhibit 4.** Solution Space of Possible Outputs by the Firm and 1 Stakeholder



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.

Second, we decouple the problem into its constituent loops. In order to do so, we must track input-output mappings – for example, the contribution of  $O_{O1}$  toward the creation of  $O_{A1}$ . This necessarily makes assumptions about the production function of Stakeholder A. In more complex cases we find it convenient to specify input-output mappings, reflecting the fact that not all

inputs are simultaneously required to produce each output of the firm.

Given the decoupled, constrained loop problem, we can analyze each output's contribution to the satisfaction of the organization. Conveniently, it can be shown that this system of equations is linear in these contributions, and therefore, we can use superposition to reconstruct the total satisfaction achieved and the desired prioritization of outputs. Substituting Equations 1-3a into 4, we are left with the following contribution of  $O_{O1}$  to the organization's satisfaction:

$$(S_o)_{O1} \mid n_{A1O} (p_a n_{O1A} O_{O1})^\zeta \geq 2 n_{A2O} (p_a n_{O1A} O_{O1})^\zeta \geq 4 \frac{O_{O1}}{p_o} \quad (5)$$

Given this formulation, we can prune weak loops. If we first assume a unit output and a known value of  $p_o$ , we can compute whether or not the contribution to satisfaction is greater than zero. Loops that do not provide positive satisfaction should be excluded from further calculations. This rough calculus of cost/benefit enables us to reduce complexity in this model. After pruning, we can next calculate the outputs that maximize satisfaction.

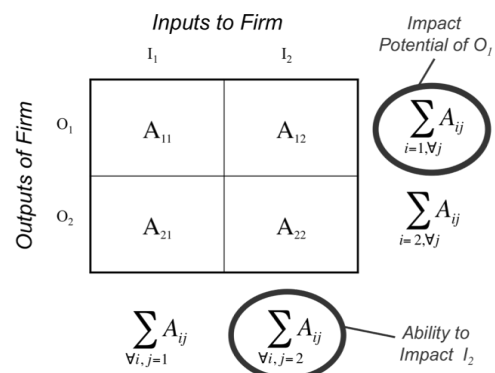
$$O_{O1}^{max} \mid (\zeta p_o)^{14\zeta} (n_{A1O} \geq 2 n_{A2O})^{14\zeta} (p_a n_{O1A})^{14\zeta} \quad (6)$$

Given the system is symmetrical in  $O1$  and  $O2$ , we can infer the solution for  $O_{O2}$  and could demonstrate that it is less than the resource constraint.

Exhibit 4 shows the feasible solution space and the optimal allocation of resources for the simplest exchange, with one flow in either direction. We can see that the non-linearity in utility at the origin stakeholder is sufficient to produce an interior solution, consistent with the formulation exhibiting diminishing marginal rates of substitution among the inputs to the organization. We can also superimpose the fully non-linear solution, to demonstrate the compromise made by assuming linear stakeholder utility. The difference between the two solutions is the error we incur by requiring computations proceed in parallel.

In order to illustrate the symmetry of the formulation, we can summarize the network as a matrix ( $A$ ). We will populate individual cells  $A_{ij}$  with a summary metric of connection strength for all paths from  $O_i$  to  $I_j$ . Each  $A_{ij}$ , therefore, represents the ability of  $O_i$  to influence  $I_j$ . Having constructed  $A$ , 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 (Exhibit 5). This sum already incorporates how important the input is to the organization. This matrix

**Exhibit 5.** Influence matrix  $A_{ij}$



also provides a methodology for understanding how well the 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.

As a sanity check on the system, we can check the distribution of utilities the firm receives, which should correspond to a manager's intuitive understanding of the relative importance of inputs. Writing Equation 5 in terms of  $O_{A1}$  and  $O_{A2}$  instead of for  $O_{O1}$ , we can solve for Stakeholder A's outputs at the satisfaction maximizing solution for  $O_{O1}^{max}$ . This yields

$$(O_{A1}^{max})_{O1} | (\zeta p_o p_A n_{A10} n_{O1A})^{\frac{1}{14\zeta}} \quad (7a)$$

$$(O_{A1}^{max})_{O2} | (\zeta p_o p_A n_{A10} n_{O2A})^{\frac{1}{14\zeta}} \quad (7b)$$

$$(O_{A1}^{max}) | (O_{A1}^{max})_{O1} 2 (O_{A1}^{max})_{O2} | (\zeta p_o p_A n_{A10})^{\frac{1}{14\zeta}} (n_{O1A}^{\frac{1}{14\zeta}} 2 n_{O2A}^{\frac{1}{14\zeta}}) \quad (7c)$$

If we follow the same process to generate for  $O_{O2}^{max}$ , we can take their ratio to find that

$$\frac{O_{A1}^{max}}{O_{A2}^{max}} | \frac{/n_{A10} 0^{\frac{1}{14\zeta}}}{/n_{A20} 0^{\frac{1}{14\zeta}}} \quad (8)$$

Substituting Equation 8 into Equation 1, and taking the ratio of the instantiations for A1 and A2, we have

$$\frac{U_{A1}}{/n_{A10} 0^{\frac{1}{14\zeta}}} | \frac{U_{A2}}{/n_{A20} 0^{\frac{1}{14\zeta}}} \quad (9)$$

Having solved a simplified case, it is easy to extrapolate the solution with n nodes in a loop. For each path through the network with A,B,...Z stakeholders starting with  $O_{O1}$ , the contribution to that Output's importance is

$$O_{O1}^{path1} | (\zeta p_o)^{\frac{1}{14\zeta}} (n_{Z10})^{\frac{1}{14\zeta}} (p_a p_b \dots p_z n_{O1A} n_{A1B} \dots n_{Y1Z})^{\frac{\zeta}{14\zeta}} \quad (10)$$

If we sum this statistic for all paths through the network that begin with  $O_{O1}$ , then we have a measure of how important  $O_{O1}$  is relative to the other possible outputs of the firm. *This is the summary statistic we will use to capture the importance of a path through the network.* It is Equation 8 that computes the statistic for our matrix entries  $A_{ij}$

This networked approach enables us to deal with the fact that one cannot always interact directly with all of the stakeholders who are important to the firm. Although we have not directly defined the weightings for individual stakeholders, this methodology provides the direct answer to the underlying question of prioritizing among outputs. This was accomplished by expanding from a direct, two-party transaction to a generalized exchange model.

In the following section, we introduce a model of a firm operating in a complex stakeholder environment to illustrate the operational context for the generalized exchange theory.

### Multinational Resource Extraction Example

In this section, we showcase a corporate strategy situation to illustrate the indirect exchange behavior previously

discussed. This case study is inspired by a four year study we conducted with a multibillion dollar firm, ConExRon, but simplified for explanatory purposes, and with representative data replacing the real data. ConExRon is a large multinational with expertise in the extraction of a natural resource. They have built complex systems on five continents to extract resources. The design of the extraction systems constructed is location-specific, as is the majority of the building effort. The firm has yearly revenues of 100 Billion USD, and employs ~100,000 people worldwide. The firm is vertically integrated, with expertise in the identification, extraction, processing, and distribution of the resource. As such, they have a range of stakeholders along the supply chain, in addition to the end-customers (consumers), the firm's investors, and others, as described next.

ConExRon recently secured the rights to a significant reserve in a foreign country by creating a joint venture with a local firm. ConExRon is now faced with the challenge of creating a multi-billion project in a foreign environment with an unknown partner. While the project will be technically challenging, there are early indications that the complexity of the external relations will pose the most significant risk to the completion of the project. The federal government has a history of renegotiation and has recently nationalized a competitor's operation. The local government has sole authority over environmental compliance, which it may withhold to boost local content. Finally, the joint venture partner is already requesting an exchange of research scientists, with a view to increasing technology transfer. The firm will have to create a system that is capable of obtaining what it needs from all of these partners, while operating at an acceptable cost and preserving its proprietary expertise.

We begin by illustrating the actors and their inter-relationships on a network diagram, shown in Exhibit 6. There are many exchanges illustrated in this diagram. Examples of direct transactions include:

- Obtaining subsystems from Suppliers, in exchange for contracts
- Providing return on investment to Investors in return for investment
- Selling the final product to Consumers

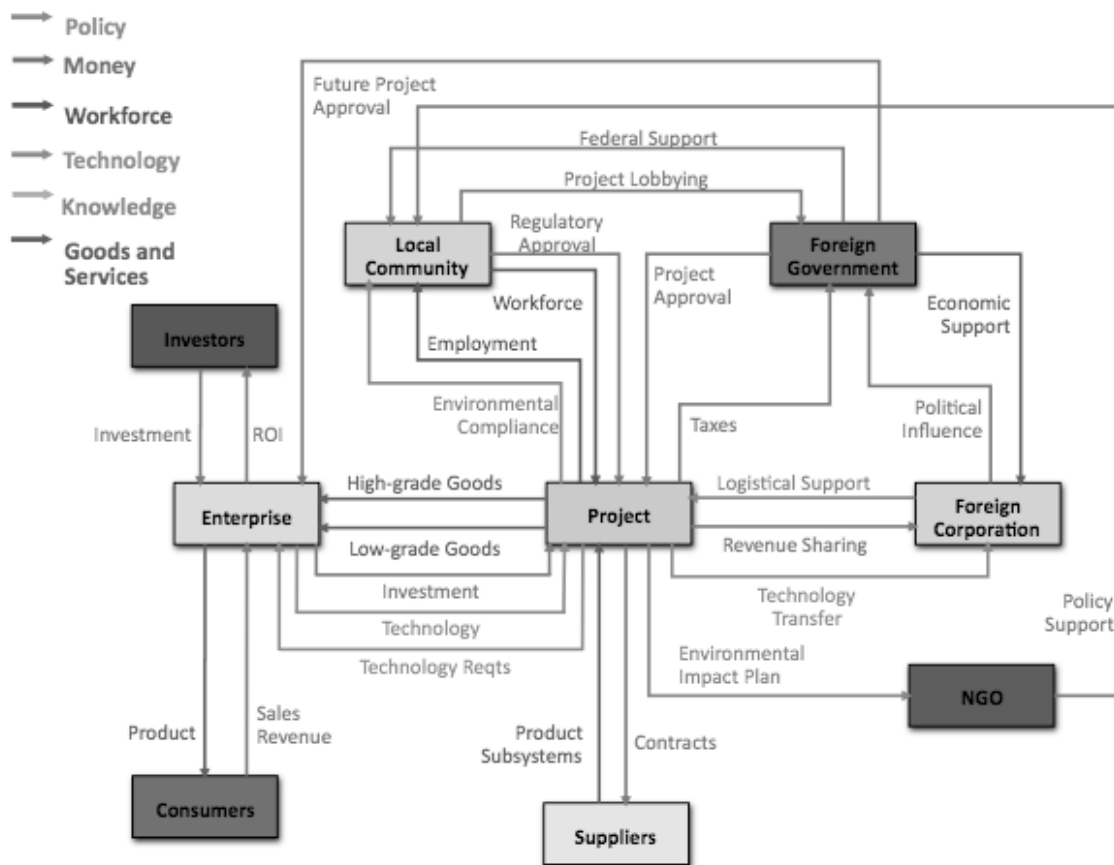
Examples of indirect transactions include:

- Sharing technology with the Foreign Corporation, which exercises political influence over the Federal Government to secure project approval.
- Enabling the NGO to critique the Environmental Impact Plan, who provides support for the project to the local government, in order to obtain regulatory approval.
- Employing sectors of the local economy to encourage the Local Community to lobby the Federal Government for future contracts.

These examples all represent possible courses of action for the firm. More specifically, they all illustrate outputs of the enterprise or the project which will need to be prioritized in order to secure the resources necessary to complete the project. Sample decisions that ConExRon will have to make include:

- Is a substantial Technology Transfer program necessary to acquire the support of the Foreign Corporation, as compared with Revenue Sharing?
- Which of the supporting actions available for securing Regulatory Approval is more impactful (Environmental Compliance or the Environmental Impact Plan)?
- What options exist for improving the likelihood of Future Project Approval?

**Exhibit 6.** Network diagram for ConExRon



The following section provides one possible numerical method for prioritizing the outputs of the firm.

### Numerical Results

In Section 3, we developed a general, parameterized method for prioritizing the outputs of the firm. Here we set up the network to enable an analysis of the important outputs of ConExRon. Given that we have already outlined how to construct the model, we must now assign values to the variables in Equation 8 for each link in the network, and then use Equation 8 to compute the ranking for each possible loop in the network.

The first variable we address is needs ( $n_i$ ). In Cameron (2010), we defined a method of eliciting the needs ( $n_i$ ) from individual stakeholders. This method is explicitly set up to enable each stakeholder to rank their own needs, such that this aspect of the model is purely driven by stakeholder data. We used a modified Kano analysis (Walden, 1993), first defining the type of need as Must Have (strong expectation of satisfaction), One Dimensional (linear utility in increased achievement), or Exciter (low expectation of satisfaction). We then augmented these need types using an anchored importance scale to enable stakeholders to differentiate between needs of the same type (e.g., Must Have). Using this analysis frame, we built a questionnaire for eliciting these parameters directly from stakeholders. In Cameron (2010), we demonstrated this method of needs characterization by constructing a model from stakeholder inputs.

While this methodology is set-up to enable each stakeholder to rank their own needs, for the purposes of this example, the authors ranked the needs for all stakeholders in the model consistent with the authors' experience in this industry. We rank

needs on a scale of [0.10,1], setting a lower bound of 0.10 to reflect the fact a link of value zero could simply be removed from the network without effect.

On the top end of the scale, Regulatory Approval for Project from the Local Community was set to 1.0, as was Federal Support from the Foreign Government to the Local Community. On the low end, Workforce from the Local Community to the Project was set to 0.2, as was Political Influence from the Foreign Corporation to the Foreign Government.

We then set the remaining variables ( $\nabla=1/2, p=1$ ) such that stakeholders convert received utility into outlaid resources, in keeping with the assumption that stakeholders break-even on utility received vs. outlaid resources. This reduces the comparison statistic (Equation 8) into a ranking of loops by the multiplicative sum of all the needs carried along that path, except with the need of the origin stakeholder squared. Thus we have a very simple calculation to complete in order to perform this analysis – a multiplication of the needs.

Examining the top loops produced is a useful sanity check on these need rankings—we simply rank loops by the comparison statistic (from Equation 8). We can immediately tell that Regulatory Approval is important to the project, in that it appears in 5 of the top 10 loops (Exhibit 8). Return on investment is best delivered through high-grade goods, as opposed to low grade goods. Finally, we can also note the incidence of indirect transactions. Clearly, strong needs are required to keep indirect transactions afloat, in that each additional link (on average) acts to reduce the loop's score. Given this environment, the model produces results that enable us to compare the importance of indirect transactions against direct transactions.

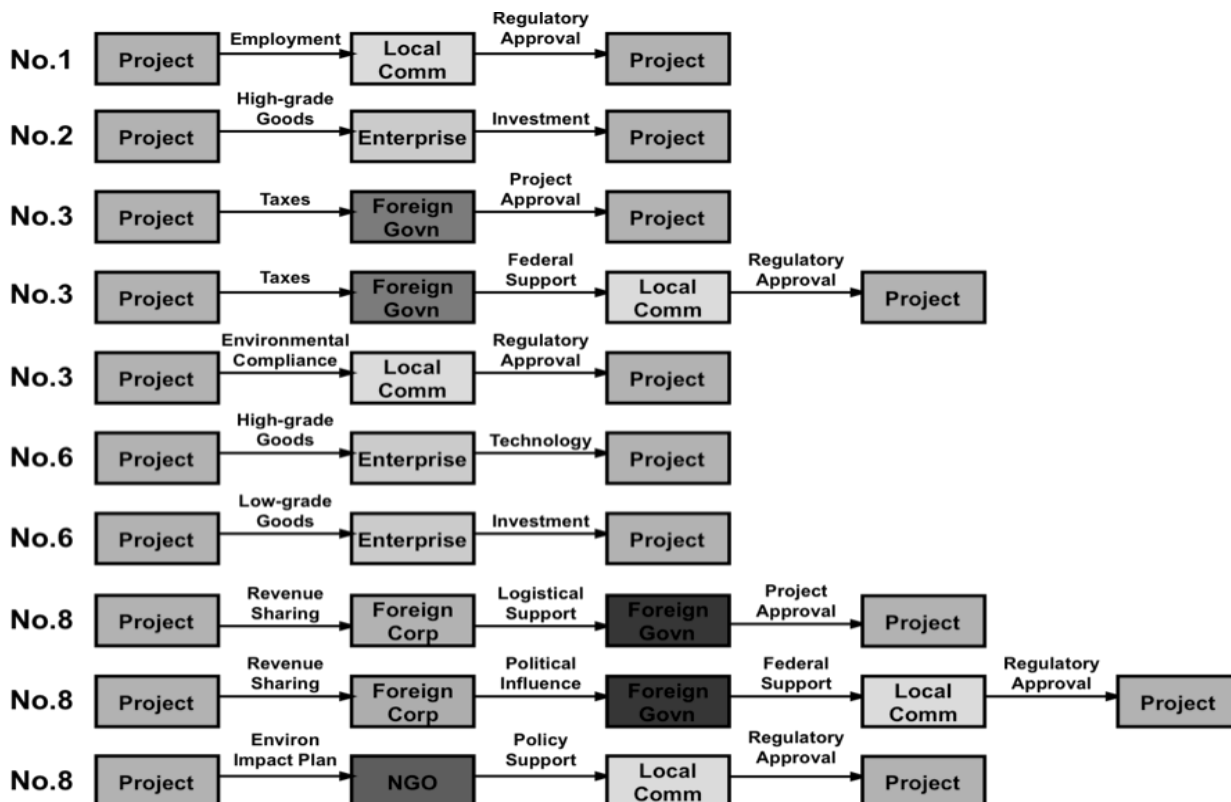
Turning to the stated goal of this article, the model calculates the relative priority of the firm's outputs (Exhibit 7). This amounts to the sum of all loops started by each output, or in terms of the influence matrix *A*, it is the comparison of the row-wise sum of the elements.

**Exhibit 7.** Priority of Firm Outputs

Rank	Firm's Output
1	Employment to Local Community
2	Taxes to Foreign Government
3	High-grade goods to Enterprise
4	Environmental compliance to Local Community
5	Revenue sharing to Foreign Corporation
6	Technology requirements to Enterprise
6	Low-grade goods to Enterprise
8	Environmental Impact Plan to NGO
9	Technology transfer to Foreign Corporation
10	Contracts to Suppliers

Interestingly, the production of High-Grade Goods is not the most important output. This is reflective of the fact that the goods cannot be extracted without the presence of several approvals, where the needs have been set such that the approval is not an insignificant act of the Local Community and the Foreign Government. The network has, therefore, captured precedence relationships (approval is needed for the production of High-Grade Goods).

**Exhibit 8.** Top ten Loops Originating from the Project



Additionally, we can see that the direct links to the Foreign Government and the Local Community are more effective than using the Foreign Corporation as an intermediary. This is not to say that the Foreign Corporation is not a useful partner, but simply that the Project should take deliberate ownership of interactions with the government bodies where possible.

Despite the interest the Foreign Corporation may have in Technology Transfer, it is clear from this analysis that Revenue Sharing is a more powerful negotiating tool, where the success of the Project is concerned. This aligns conveniently with the overall needs of the Enterprise, where technology as the dominant driver of long term profitability needs to be very carefully held and for whom revenue sharing on a limited project is a more desirable bargaining token.

### Implications for Managers

From a management perspective, this analysis suggests that it is not sufficient to consider only direct relationships with clients and stakeholders. Where the firm is organized by output functions (production, logistics/suppliers, government relations, etc.), it not sufficient to allocate resources among functions solely according to direct relationships. For example, failure to coordinate production efforts with government relations to ensure employment to the Local Community could place the project's approval in jeopardy. Peripheral players can enable important loops, even though their outputs are of low individual benefit. Devising a strategy for the project implies prioritizing actors by their involvement in important transactions, direct or indirect.

Specifically with respect to the sample decisions listed in Section 4:

- While Revenue Sharing is more important than Technology Transfer to the Foreign Corporation, but given their proximity in ranking in Exhibit 7, a Technology Transfer program is likely necessary.

- Environmental Compliance is a much more impactful mechanism for securing Regulatory Approval than the Environmental Impact Plan, as evidenced by a higher ranking in Exhibit 7, as well as its presence in the Top 3 strongest loops.
- Of the mechanisms available for securing Future Project Approval, Taxes are the most powerful link to the Foreign Government. This suggests that the Project should quantify how Future Projects might impact future taxes first, before attempting to use the indirect influence of the Foreign Corporation to lobby for approval.

In addition to the static network view presented here, this methodology can also help evaluate options for rising issues. Given an underserved client or unrealized relationship, we can ask “what levers are available?” In this framework, we would think of changing the importance of needs, facilitating new links, or adding/removing actors. For example, the Project could strengthen its negotiating position with the foreign corporation vis-à-vis Revenue Sharing by lobbying to change their perceived need for Technology Transfer. Alternatively, the Project could examine its Supplier relationships to facilitate new links between its Suppliers and the Foreign Corporation, or conversely, apply pressure to the Foreign Corporation’s existing Suppliers to attempt to remove them from the network.

We have thus added another level of depth to the engineering management task of translating needs into requirements—we have shown a computable, non-arbitrary method for prioritizing among the needs of many stakeholders. This needs analysis could easily precede a QFD or balanced scorecard analysis, enabling an engineering manager to build depth and explicitly list assumptions in the prioritization of needs. Further, by constructing a network, we enable a number of completeness checks – do all outputs correspond to customer needs? Do we have a mechanism for obtaining all of the project inputs required? Do we have a metric for all important project outcomes? This completeness check has been previously highlighted as a critical factor in developing project metrics (Kaplan, 2001).

## Conclusion

Choosing a business strategy requires firms to make decisions among many possible activities and outcomes, with the goal of best satisfying the needs of the firm. These strategic decisions reveal the preferences of the firm among its clients, suppliers, and partners, as well as among the needs of the firm. In this article, we have developed a methodology to compare the firm’s knowledge of its networked environment with the priority of its needs. This enables the firm to make explicit decisions about its needs, and the feasibility of satisfying them with the firm’s production function.

In order to solve this problem, a scalable mathematical representation of indirect transactions has been built on a foundation of a theory of generalized exchange. This model satisfies basic behaviors of a microeconomic model, and does so while enabling concepts of exchange that are not easily monetized, such as regulatory approval. While the example chosen uses a number of simplifying assumptions to generate a closed solution, this system can also be used with more intelligent models of actors and more complex production functions.

Empirical testing of this theory is an important next step. Several possible approaches are possible – a first cycle would use case studies to capture real stakeholder networks and preferences, coupled with study participant predictions of output prioritization

and stakeholder importance, compared against realized firm inputs. In particular, it would be possible to test the hypothesis that actors often consider only direct exchanges – executing the analysis on a network restricted to direct transactions, compared against the full network.

## References

- Agle, Bradley, Ron K. Mitchell, and Jeffrey A. Sonnenfeld, “Who Matters to CEOs? An Investigation of Stakeholder Attributes and Salience, Corporate Performance, and CEO Values,” *Academy of Management Journal*, 42:5 (1999), pp. 507-525.
- Akerlof, George A., “The Market for Lemons: Quality Uncertainty and the Market Mechanism,” *Quarterly Journal of Economics*, 84:3 (1970), pp. 488-500.
- Albanese, Robert, and David D. Van Fleet, “Rational Behavior in Groups: The Free-Riding Tendency,” *Academy of Management Review*, 10:2 (1985), pp. 244-255.
- Arrow, Kenneth J., “Uncertainty and the Welfare Economics of Medical Care,” *Journal of Health Politics, Policy, and Law*, 26:5 (2001), pp. 851-883.
- Arrow, Kenneth J., and Gerard Debreu, “Existence of an Equilibrium for a Competitive Economy,” *Econometrica* 22:3 (1954), pp. 265-290.
- Botta, Rick, and A. Terry Bahill, “A Prioritization Process,” *Engineering Management Journal*, 19:4 (2007), pp. 20-27.
- Cameron, Bruce G., Edward F. Crawley, Geilson Loureiro, Eric S. Rebenisch, “Value Flow Mapping: Using Networks to Inform Stakeholder Analysis,” *Acta Astronautica* 62:4-5 (2008), pp. 324-333.
- Cameron, Bruce G., Theodore Seher, Edward F. Crawley, “Goals for Space Exploration Based on Stakeholder Network Value Considerations,” *Acta Astronautica*, 68:11-12 (2010), pp. 2088-2097.
- Cyert, Richard M., and James G. March, *A Behavioral Theory of the Firm*, Wiley-Blackwell (1992).
- Damian, Daniela, “Stakeholders in Global Requirements Engineering: Lessons Learned from Practice,” *IEEE Software*, 23:2 (2007), pp. 21-27.
- Donaldson, Thomas, and Lee E. Preston, “The Stakeholder Theory of the Corporation: Concepts, Evidence, and Implications,” *Academy of Management Review*, 20:1 (1995), pp. 65-91.
- Dyer, Jeffrey H., and Kentaro Nobeoka, “Creating and Managing a High-Performance Knowledge-Sharing Network: the Toyota Case,” *Strategic Management Journal*, 21:3 (2000), pp. 345-367.
- Cheng, Betty, Joanne Atlee, “Research Directions in Requirements Engineering,” *Future of Software Engineering*, (2007), pp. 285-303.
- Ekeh, Peter P., *Social Exchange Theory: The Two Traditions*, Harvard University Press (1974).
- Faust, Katherine, and Stanley Wasserman, *Social Network Analysis: Methods and Applications*, Cambridge University Press (1995).
- Frederick, William C., “From CSR1 to CSR2: The Maturing of Business-and-Society Thought,” *Business and Society*, 33:2 (1994), p. 150.
- Freeman, R. Edward, *Strategic Management: A Stakeholder Approach*, Boston Pitman (1984).
- Hardin, Garrett, “The Tragedy of the Commons,” *Science*, 162:3859 (1968), pp. 1243-1248.
- Homans, George C., and David M. Schneider, *Marriage, Authority, and Final Causes: A Study of Unilateral Cross-Cousin Marriage*, Free Press (1955).



- Jackson, Matthew O., and Asher Wolinsky, "A Strategic Model of Social and Economic Networks," *Journal of Economic Theory*, 71:1 (1996), pp. 44-74.
- Johnson, William H., and David A. Johnston, "Aligning Technical and Business Goals in Industry-University Collaborative R&D Projects: A Tale of Two Projects," *Engineering Management Journal*, 13:1 (2001), pp. 44-74.
- Kaplan, Robert S., and David P. Norton, *The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment*, Harvard Business School Press (2001).
- Karlsen, Jan T., "Project Stakeholder Management," *Engineering Management Journal*, 14:4 (2002), pp. 19-25.
- Kauffmann, Paul, Resit Unal, Abel Fernandez, and Charles Keating, "A Model for Allocating Resources to Research Programs by Evaluating Technical Importance and Research Productivity," *Engineering Management Journal*, 12:1 (2000), pp. 5-8.
- Keeney, Ralph L., Howard Raiffa, and David W. Rajala, "Decisions with Multiple Objectives: Preferences and Value Trade-Offs," *IEEE Transactions on Systems Management and Cybernetics*, 9:7 (1979), p. 403.
- Kirchhoff, Bruce A., Matthias J. Merges, and Joe Morabito, "A Value Creation Model for Measuring and Managing the R&D Portfolio," *Engineering Management Journal*, 13:1 (2001), pp.19-23.
- Locke, Richard M., and Alvin J. Siteman, "The Promise and Perils of Globalization: The Case of Nike," in: Kochan Thomas A., and Richard Schmalensee (eds) *Management: Inventing and Delivering Its Future*, MIT Press (2003).
- Lim, Soo Ling, Daniele Quercia, Anthony Finkelstein, "StakeNet: Using Social Networks to Analyse the Stakeholders of Large-Scale Software Projects," *Proceedings of the 32<sup>nd</sup> ACM/IEEE International Conference on Software Engineering* (May 2-8, 2010).
- Magill, Michael, and Martine Quinzii, "The Probability Approach to General Equilibrium with Production," *Journal of Economic Theory*, 39:1 (2009), pp. 1-41.
- Mitchell, Ron K., Bradley R. Agle, and Donna J. Wood, "Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and What Really Counts," *Academy of Management Review*, 22:4 (1997), pp. 853-886.
- Nalebuff, Barry J., and Joseph E. Stiglitz, "Information, Competition, and Markets," *American Economic Review*, 73:2 (1983), pp. 278-283.
- Orts, Eric W., "Beyond Shareholders: Interpreting Corporate Constituency Statutes," *George Washington Law Review*, 61:14 (1992).
- Penserini, Loris, Anna Perini, and Angelo Susi, "From Stakeholder Needs to Service Requirements," *Proceedings of the Int. Workshop on Service-Oriented Computing: Consequences for Engineering Requirements (SOCCER'06) RE'06 Workshop*, Minneapolis, Minnesota, USA, Sept 12th, 2006, pp. 8, IEEE CS Digital Library. DOI Bookmark: <http://doi.ieeecomputersociety.org/10.1109/SOCCER.2006.4>.
- Pleon Kohtes Klewes (GmbH), "Geheime Mission? Deutsche Unternehmen im Dialog mit kritischen Stakeholdern: Eine Umfrage unter den 150 grossten Unternehmen" (2004), ? [www.ketchum.de/files/Geheime\\_Mission.pdf](http://www.ketchum.de/files/Geheime_Mission.pdf).
- Prendergast, Canice, "The Provision of Incentives in Firms," *Journal of Economic Literature*, 37:1 (1999), pp. 7-63.
- Roloff, Julia, "Learning from Multi-Stakeholder Networks: Issue Focused Stakeholder Management," *Journal of Business Ethics*, 82:1(2007), pp. 232-250.
- Rowley, Timothy J., Dean Behrens, and David Krackhardt, "Redundant Governance Structures: An Analysis of Structural and Relational Embeddedness in the Steel and Semiconductor Industries," *Strategic Management Journal*, 21:3 (2000), pp. 369-386.
- Rowley, Timothy J., "Moving Beyond Dyadic Ties: A Network Theory of Stakeholder Influences," *Academy of Management Review*, 22:4 (1997), pp. 887-910.
- Smith, Ken G., Terence R. Mitchell, and Charles E. Summer, "Top Level Management Priorities in Different Stages of the Organizational Life Cycle," *Academy of Management Journal*, 28:4 (1985), pp. 799-820.
- Thurston, Deborah L., "Multiattribute Utility Analysis in Design Management," *IEEE Transactions on Engineering Management*, 37:4 (1990), pp. 296-301.
- Walden, David, "Kano's Methods for Understanding Customer-Defined Quality," *Center for Quality of Management Journal*, (1993), pp. 3-36.
- Willer, David, *Network Exchange Theory*, Praeger Publishers (1999).
- Yamagishi, Toshio, and Karen S. Cook, "Generalized Exchange and Social Dilemmas," *Social Psychology Quarterly*, 56:4 (1993), pp. 235-248.

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