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Group Decision-Making

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctorate of Philosophy at Virginia Commonwealth University.

by

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Abstract

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The present work explores improvements in group decision-making. It begins with a practical example using state-of-the-art techniques for a complex, high-risk decision. We show how these techniques can reveal a better alternative. Although we created an improved decision process, decision-makers were apt to protect their own organizations instead of the project. This tendency was reduced over the course of the decision-making process but inspired the first conceptual component of this work.

The first concept describes the “Cost of Conflict” that can arise in a group decision, using game theory to represent the non-cooperative approach and comparing the outcome to the cooperative approach. We demonstrate that it is possible for the group to settle on a non-Paretto Nash equilibrium. The sensitivity of the decision-maker weights is revealed which led to the second conceptual portion of this work.

The second concept applies social network theory to study the influence between decision-makers in a group decision. By examining the number and strength of connections between decision-makers, we build from intrinsically derived weights to

extrinsically derived weights by adding the network influences from other decision-makers. The two conceptual approaches provide a descriptive view of non-cooperative decisions where decision-makers still influence each other. These concepts suggest a prescriptive approach to achieving a higher group utility.

Chapter 1. Introduction

Our aim in this work is to improve group decision-making, examining cooperative and non-cooperative group decisions in three studies. First, we implemented state-of-the-art methods in group decision theory and multi-attribute utility theory for high-value decision at a Fortune 100 company to demonstrate the value of a cooperative group decision amongst the executives. Second, we study the potential loss when the cooperative group approach is not used, which we call the “Cost of Conflict”. Finally, we study the influence individual stakeholders can have on a cooperative group decision using social network theory.

1.1. Individual and Group Decisions

In the last one hundred years, the understanding of decision-making has advanced across a number of fields. With structural underpinnings from philosophy and mathematics, decision analysis has been further enhanced by the understanding of human cognition from psychology and economics. The flow of decision theory’s development began with the individual decision-maker and was described by Keynes (1921), Ramsey (1926), and de Finetti (1937, 1949) by modeling a rational, sequential process. In this initial work, the process was wholly owned by the individual decision-maker but even at this early stage, notions of game theory began to come through as seen in de Finetti’s work (de Finetti 1949) in which a game context is considered. It is not just the single decision-maker who can have influence on the final outcome of a decision process. The decision-maker plays a role in the “market” of the decision as one would in a financial market. This idea of a market introduces the decisions of others as important or at least of impact to the decision process of the individual decision-maker. The inauguration of game theory came with the landmark work of von Neumann and Morgenstern (1944) who for the first time fully described a coherent approach to games that was both mathematically rigorous and predictive.

Although game theory would later become important to understanding the group decision process and how individuals could come together to make a group decision, in these earlier stages of development, decision analysis remained largely focused on the decision process of the individual decision-maker. The work built from single objective decisions and then moved on to advance into work on multi-objective decisions. Significant work still remains to be done in the understanding of group decision-making. Moreover, the approach of expanding from the understanding of the individual decision-maker to describe the group decision may not be sufficient to create both a description of how decisions are made and a direction on how the could be improved. Game theory may provide that needed tool.

1.2. Decision Analysis for Group Decisions

Broadly group decision can be thought of as any decision where a group of two or more individuals must jointly decide from a set of outcomes which impact all of the individuals in the group. For focus, this work will not include three classes of group decision-making as described by Keeney (2013). “One class is negotiations, because the individual negotiators are trying to best satisfy their own objectives rather than the group’s objectives, and each individual has veto power. A second class of decisions ruled out is voting situations where all votes are tabulated to select an alternative according to a pre-specified rule, such as the candidate with the most votes wins. In this case, there is a collection of individual decisions by the voters that leads, with no specific group action, to a selected alternative. The third class of decisions is social planning or social welfare decisions where an individual planner or organization, after taking judgments and preferences of individuals affected by the decision into account, makes the decision."

Early attempts to develop group decision-making theory began with the individual utility constructs and then expanding from there by aggregating those utilities through some function, but problems arose. Arrow's Impossibility Theorem (Arrow 1951) was one of the first to show that the aggregation was likely to result in the group utility matching that of only one decision-maker. The solution to the problems of extending individual decision-making to group decision-making has been approached in several different ways. First, Raiffa (1968) posited the application of a group utility function and also a group probability distribution which can then be used to calculate a group expected utility for every alternative in the decision hierarchy. Others extended this approach through a Bayesian view (Seidenfeld 1989, Mongin 1995, 1998, Gilboa 2004). All of these suffered from the underlying issue of the applicability of applying a Bayesian approach to a group. The second approach which Keeney and Raiffa (1976) described was to develop a group utility function directly. Aumann (1976) and Clemen & Winkler (1999) and O'Hagan (2006) worked to understand approaches to obtain group probabilities for each event so that the expected utility could be derived from there.

All of these approaches have issues. Mongin (1995) concluded that the only consistent aggregation would be through a dictator who would aggregate according to one individual (likely the dictator) of the group thus making the group's aggregations those of the individual. Arrow (1951) began this process of seeing the limits of aggregations approaches with his impossibility theorem which showed that fairness to each individual would be lost as their preferences are brought together with any kind of ranking function. This approach of aggregating individual decision has stymied many in their attempts to bring it to coherence and match experimental results.

Keeney & Nau (2011) describe a two-stage process to overcome these issues. First, the group members develop a common understanding of the decision problem and then each evaluates the alternates from their individual perspective. Second, the group collectively evaluates the alternatives using the individual evaluations as inputs. They start with the axioms of expected utility applied to acts whose outcomes depend on previous events (the individual perspective) and add a State-Independence axiom which separates subjective probabilities for events from the utility of the outcomes. The probabilities are independent of the state space of outcomes. With these axioms, Keeney & Nau (2011) declare: "If the group preferences also satisfy an independence condition stating that only the marginal distributions of the members' utilities are relevant and that any one member has sovereignty over group choices that affect only herself, then it follows that the group effectively has state-dependent expected utility preferences over the original set of acts, which are represented by a weighted sum of the state-independent expected-utility functions of the individual members. The values of the weights depend on both the members' relative strengths of preference among the alternatives and the relative importance of the members in the group. If the group members are in agreement on these parameters, then appropriate values for the weights can, in principle, be determined by separate consideration of these issues."

Keeney (2013) steps away from much of the problems of extending individual decisions to group decisions by removing the implicit assumption that each of the group members hold the same frame for their decision problem as the other decision-makers. This means that each decision-maker is concerned with the same consequences and each considers all of the events to matter. To broaden the applicability of the approach Keeney (2013) assigns different probabilities to specific events for each decision-maker and different utilities to specific consequences for each decision-maker. Finally, each decision-maker can have a different view on the impact of the consequences. This construction makes the previous Keeney & Nau (2011) formulation a special case. With the decision frame broadened, Keeney (2013) outlines both a procedure and a formulation for how the decision will be made. The procedure has the individuals create their own view of the decision including their individual weighting of outcomes which allows for zero weighting if the outcome is of no consequence to the individual. The individual values are then brought together in a weighting function that must be determined through some process such as equal weighting or percentage ownership, or seniority, or some other formulation. Keeney solves the original issue of Arrow's Impossibility Theorem and develops his analysis from a broad set of axioms, but he leaves behind the work to create a rigorous approach to balancing the weighting of each individual's impact to the overall group decision.

The multitude of previous attempts from Raiffa (1968), Hylland & Zeckhauser (1981), Seidenfeld et al. (1989), and Mongin (1995) to describe a generalized approach to a group decision have all resulted in an impossibility theorem. This makes Keeney (2013) an important step forward. Nevertheless, the issue of ability to implement remains. This solution is that the group expected utility for an alternative is the weighted sum of the individual member's expected utilities for that alternative. The approach solves problems such as maintaining the integrity of the individual decision analysis and is explicit in how the answers of the individuals should be combined into a group answer; however, a significant issue remains. How is the group to decide what the appropriate weighting is across the individuals? This is discussed in section 4. Additionally, what happens if the group is not acting fully cooperatively with the aim of maximizing the group utility? Perhaps they may harbor some intent to maximize their own utility at the expense of the group, even if not explicitly. One possible solution is to expand the analysis frame further and not "decide" but rather "discover" how the decision-makers are interacting.

1.3. Game Theory for Non-cooperative Groups

In their seminal work, John von Neumann and Oskar Morgenstern (1944) described the first fully coherent approach to game theory. Their aim was to understand the mechanism of games and to make the connection back to economics as a way to explore other theoretical mechanisms for observed outcomes. They were looking to establish not an analogy between games and economic behavior but a true and direct relationship. They declared "that the typical problems of economic behavior become strictly identical with the mathematical notions of suitable games of strategy." von Neumann and Morgenstern (1944 p.4). With this declaration, a new field of study was born, but not just for economic understanding. Game theory would grow to impact many fields of study including decision analysis, but first, more development was needed. In the first chapter, von Neumann and Morgenstern (1944) describe game theory's purpose as a tool to understand stable institutional arrangements or "standards of behavior" for any given situation or game. The theory tries to predict what stable institutional form will emerge from any given game. The theory does not posit an *a priori* arrangement, but rather expects one to emerge out of the game play itself. It is the preferences and tastes of the players working within the rules of the game that produces the form. In this way, game theory, as described by von Neumann and Morgenstern (1944), departs from classical economic theory which describes the form first and then describes the outcomes.

H.W. Kuhn (1950, 1953) described extensive form games which allow the designer of the game mechanism to specify how the game would play out and in what order the participants would play. This understanding persists today with extensive form games becoming an entire class of study within game theory. At the same time new insights were also developing. The extensive form includes an element of time in contrast to the strategic form of a game which describes the actions and strategies of the players but not the play-by-play of the game itself. A third description, providing even less information, is the characteristic form of a game which describes the set of payoffs to players no matter what the remaining players of the game do.

Additionally, games can be described as cooperative or non-cooperative. In four papers between 1950 and 1953 John Nash made formative contributions to both non-cooperative game theory and to bargaining theory. In two papers, "Equilibrium Points in N- Person Games" (1950) and "Non-Cooperative Games" (1951), Nash proved the existence of a strategic equilibrium for non-cooperative games, now called the Nash equilibrium. Nash also described "Nash program", which defines an approach to understanding cooperative games by breaking them down to their non-cooperative component parts. In another tract of thought, Nash outlined his bargaining theory. With both of these papers, he created an axiomatic bargaining theory. With it, he proved both the existence of the Nash bargaining solution and he executed the first application of the Nash program.

Cooperative games were further advanced with the work of Aumann (1961, 1964) who showed how cooperative games could be played such that an improvement of the Nash Equilibrium was possible through trading of information about strategies by the players. In the 1970's, work also advanced on the ability of groups to make decisions impacting themselves. This research first appeared when Groves (1973) explored what happens to teams when the individuals within the team have different interests and utility curves. With divergent interests the team's action can degenerate into an (N+1)-person game where a manager must be called in to take the input of the team and convert that input into a more complete frame, so that the manager can find the best equilibrium point for the group. Effectively, the team is not deciding the outcome. Groves and Loeb (1975) solve this problem by creating a mechanism by which a central actor or agent draws out the information from the team and presents it back to them in a feedback loop that allows the team to determine the dominant strategy that reveals the best equilibrium point.

Even with this advance the prevailing attitude toward game theory as a tool to help with group decision-making (as a cooperative approach) revealed skepticism that broader applications were possible. Rasmussen (1989) typified this skepticism of applying cooperative gave theory in this articulation "Cooperative game theory may be useful for ethical decisions but its attractive features are inappropriate for most economic situations, and the spirit of axiomatic approach is very different from the utility maximization of current economic theory." While decision analysis was moving from utility theory and into predictive analysis of decisions mainly studied and researched by those in operations research, game theory largely remained the purview of economists and was used in relatively narrow sets of research. The employment of von Neumann and Morgenstern's (1944) work as a tool for decision analysis was still yet to be realized.

1.4. Outline of the Dissertation

We describe a practical implementation of group decision theory for a multi-million-dollar technology and process change at a nearly 1000-branch bank in Chapter 2. We showed that the latest methods in group decision theory could be used in practice by embedding them in the program management processes of the bank. One of the consistent issues throughout this implementation was the tendency for the decision-makers to protect their own organizations within the bank at the expense of the overall project, a tendency that was reduced over the course of the decision-making process.

Given the tendency of decision-makers to veer away from a fully cooperative approach, we developed the first of two conceptual portions of this work. Chapter 3 describes the "Cost of Conflict" that can arise in a group decision, using game theory to represent the non-cooperative approach and comparing the outcome to the cooperative group solution.

The second conceptual portion of this work, as described in Chapter 4, we use social network theory as a lens to study the influence that decision-makers can have on each other in a group decision, through the number and strength of connections between decision makers.

Chapter 2. The Value of Cooperative Group Decision Making

Decision-making in a large corporation often requires the engagement of many stakeholders. This makes it difficult to establish the criteria to evaluate strategies and to determine who will approve the final decision. This multiple stakeholder decision difficulty can be brought about by a number of dynamics. Sometimes it is driven by a desire to achieve acceptance by the stakeholders in the hopes that the change will land better with the entire organization. Sometimes it is the reliance on an organizational matrix structure that operates with the engagement of multiple stakeholders. Sometimes the complexity of the issues means no one decision-maker is able to understand, analyze, and choose an approach. Capital One was facing just such a decision. The following is a description of that decision and the practical implementation of the framework that Keeney (2013) describes as a method to execute against a multi-objective, multi-stakeholder decision.

The company had embarked on an effort to rollout a new Bank Teller system for its nearly 1000-branch network. In addition, a new technology called Branch Image Capture (BIC) would also rollout that would take an image of a check and read the handwritten and encoded information. This imaging capability would ensure the digitization of all elements of the check instead of the teller hand-keying information into the teller system, as is done in most bank branches. The implications of the change were profound. Information about the customers' transactions would be rapidly transmitted to all bank systems. Customers could view the information for their transaction immediately, instead of having to wait for it to be physically transported to an operations center for overnight processing. Also, the transactions would be "perfected" while the customer was at the teller line, meaning any issues with the transaction (e.g. mutilated checks, deposit slip errors, etc.) would be fixed immediately. This prevented the need to send "adjustment" letters to the customer explaining that a change had been made to their account. These letters could be a confusing experience for the customer often prompting them to contact the bank's call center to seek clarification.

For Capital One's cost structure, the impact was also dramatic. Millions of dollars would be eliminated since checks and other transaction documents would not be transported to operations centers for processing and fraudulent checks could be spotted rapidly since the information was transmitted immediately. Beyond transportation cost savings, there were additional savings for the operations group from reductions in transaction exceptions and the operator time necessary to resolve them. The implementation also had impacts for the Branch team. The increased functionality allowed tellers to improve conversations with customers and focus on their needs, leading to additional new accounts for all products and services across the Bank. For the technology group, this implementation meant a reduction in antiquated systems that were expensive to maintain and difficult to upgrade. Overall, this new technology led to cost reductions and improved associate engagement and customer satisfaction.

To get the full value of the effort, however, a very significant information technology upgrade was required. At its heart, three main areas needed improvement:

1. The Teller System plus the adjoining Branch Image Capture (BIC) capability

2. A new middleware to provide the connection to the mainframe that held the customer information
3. A back office (centralized for all branches) processing platform to ensure the checks were sent to other banks and the Federal Reserve to receive the funds

The second and third efforts were largely information system upgrades that had smaller impacts on associates and could be implemented in weekend conversions. This weekend implementation provided the opportunity to undo the change should a problem occur. In stark contrast, the first effort would take months to convert each branch and troubleshoot and repair problems. This was not only paramount for maintaining a good experience for customers but was also a regulatory requirement for the bank. A poor rollout could have meaningful negative impacts on the bank.

Often in a business context, the financially based business case drives the decision-maker by constraining the types of attributes that can be used to make a decision, and then forcing them to be monetized so that a discounted cash flow model (often Net-Present Value) can be employed. This is an approach mandated by most corporate finance departments in an attempt to drive a common view of large programs, especially those with significant infrastructure costs. Although a valuable tool for deciding if a project would positively impact a business, this methodology does not cover two major concerns for a successful infrastructure implementation.

Risks: Unless they are monetized, a discounted cash-flow model does not handle the review of risks. It, therefore, does not help the decision-maker to deal with these risks within the core decision framework. Instead, the decision-maker is forced to glom on some sort of risk factor to the discounted cash flow model.

Change Management: Since the implementation of a teller system is essentially a process of putting new tools into the hands of tellers so that they can serve customers, understanding how those tellers will adapt to the change and implement the new tools is key to making a good decision as to how to do the rollout of a large infrastructure project. Here again a discounted cash flow model is blind to this consideration unless the impacts are monetized.

The change would affect multiple stakeholders across the organization. The goal was to apply some of the leading ideas in decision analysis and then implement them in a practical setting. Additionally, we wished to apply stakeholder theory (Freeman 1984) from the strategic management literature to include all affected parties across the organization in the decision-making process. We elicited objectives following the findings of Bond et al. (2008, 2010) and developed multi-attribute utility functions for each stakeholder group. To understand utility dependence, we used utility trees to develop a utility function for some stakeholders (Abbas 2011). Finally, we used the group decision-making approach in Keeney (2013) to develop a group utility function increasing traceability and buy-in from the stakeholders. This also allowed the extension of previous applications of objective value-gap analysis (Merrick et al. 2005, Feng and Keller 2006) to stakeholder value-gap analysis and the development of new, superior alternatives. A multi-objective, multi-stakeholder approach to decision-making pushes the underlying theory towards greater complexity but is reflective of the complexity found in typical large corporate decisions.

Interestingly, Freeman (1980), the originator of Stakeholder Theory, implemented a form of multi-objective, multi-stakeholder decision analysis. In this application, Freeman has taken the first step to drive toward a truly inclusive approach to finalizing a decision, but this formulation has each stakeholder creating their own view of the multi-objective decision and then seeking a negotiated final group decision. This would ultimately run into Arrow's Paradox.

2.1. Developing the Group Value Hierarchy

We created the Group Value Hierarchy assigning each of the six executive stakeholder hierarchies to a different branch of the hierarchy. By creating a clear view of the hierarchy of objectives, the decision-makers were better able to understand the characteristics of the objectives and how they related to their underlying concerns. Following Keeney (1992), we constructed the objectives hierarchy by holding facilitated discussions during weekly meetings of the executives. Figure 2 shows the first two levels of that group hierarchy while Figure 1 shows the individual stakeholder hierarchy's that underlie the group hierarchy.

Although these sessions included regular updates of progress as the component elements of the technology systems were under development and testing, a goodly portion of the time was devoted to group discussion. In these sessions, objectives were brainstormed and then scrutinized by examining problems and potential shortcomings under each objective.

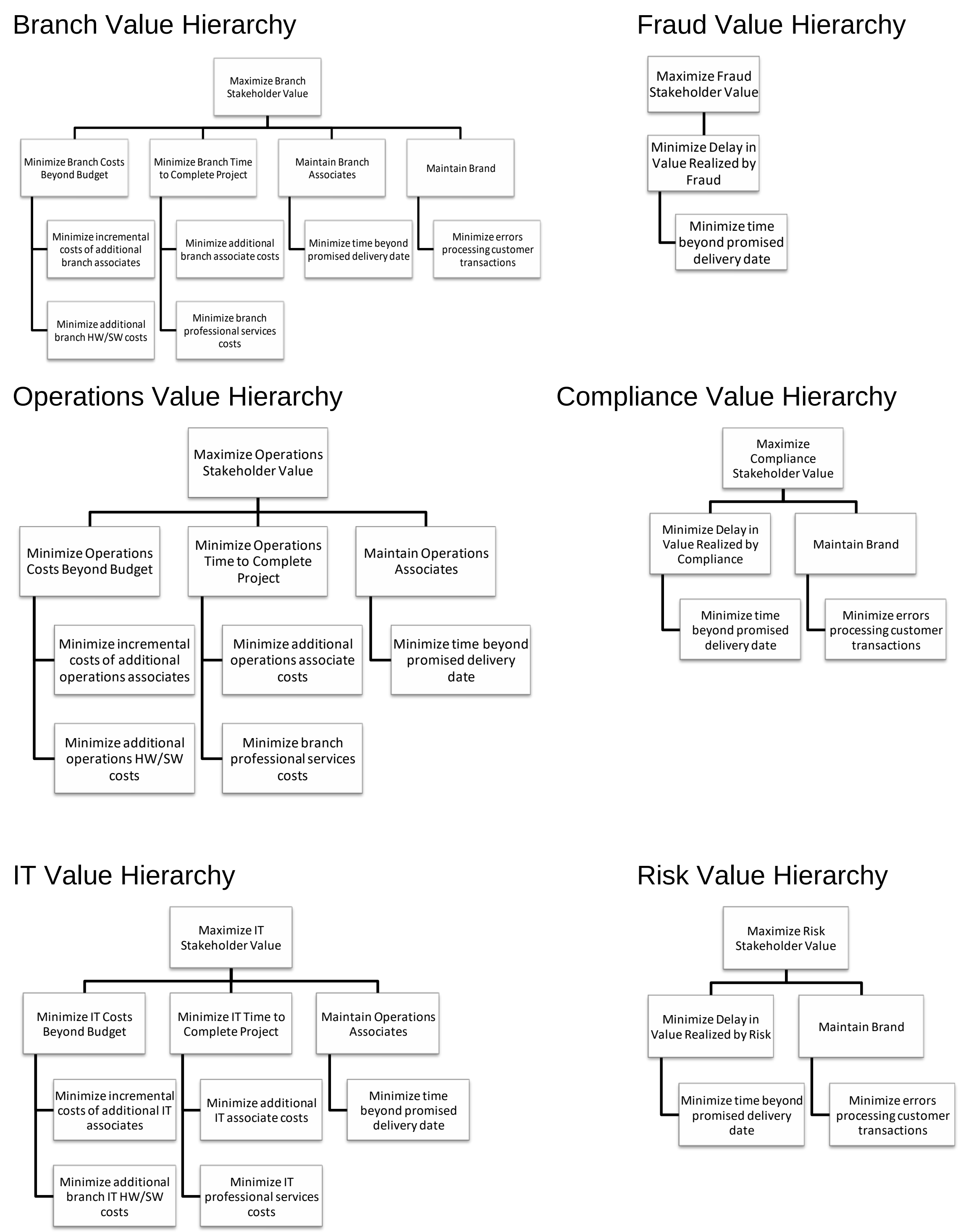


Figure 1. The Value Hierarchies of the Six Stakeholder Groups.

In the discussion, boundaries would be explored that would broaden or shrink the objective such that all were in agreement with its description. The team would then discuss the consequences of failure and success for each objective. Although this did not move to a discussion where the specifics of the value were ascribed, it did help all executives see the meaning of each objective to each executive. They came closer to a shared understanding of what each objective meant in a qualitative sense.

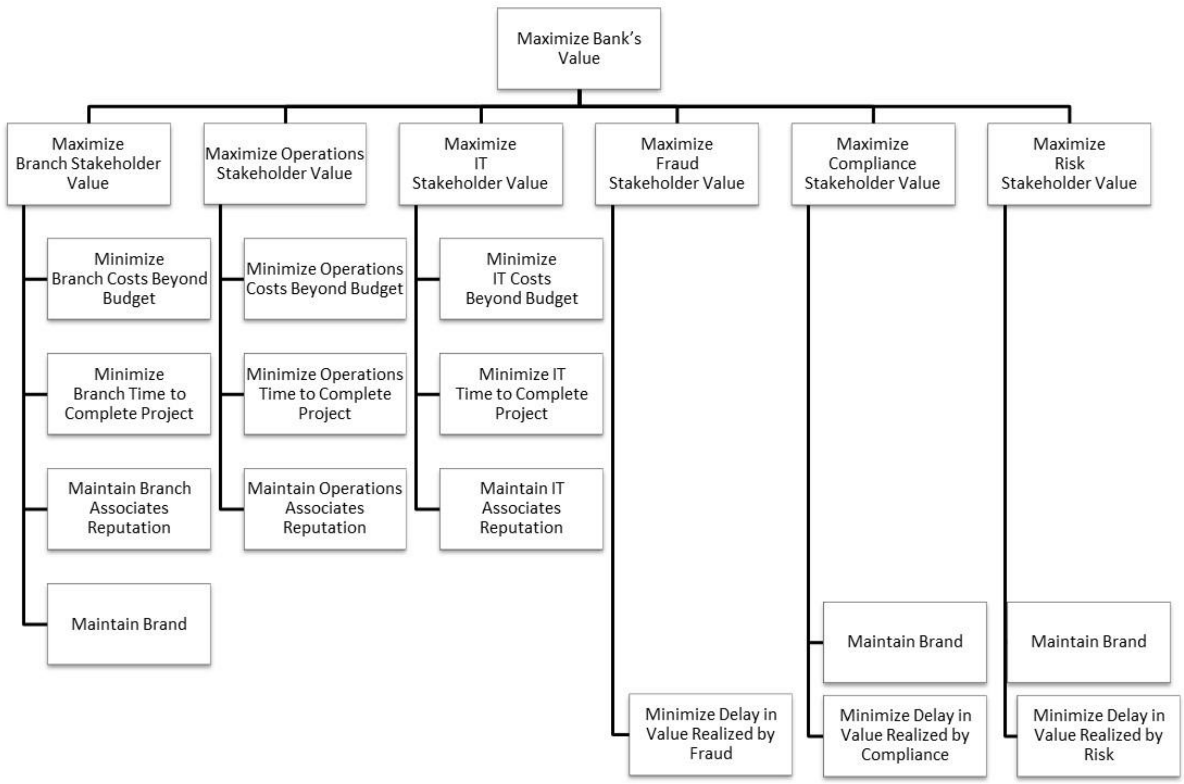


Figure 2. Top Two Levels of the Group Value Hierarchy.

2.2. Defining the utility function

The literature has several implementations using the notion of an additive value function as an appropriate model for the impact that the various objectives would have on the overall outcome. As a landmark, Kirkwood's (1997) interpretation of Dyer and

Sarin (1979) approach assumes mutual preferential independence amongst the attributes. This approach was used by Merrick et al. (2005), Feng and Keller (2006), Ewing et al. (2006) and is fairly standard across the literature. The additive value function can be written as

$$v(x_1, x_2, \dots, x_n) = \sum_{i=1}^{n} w_i v_i(x_i), \qquad where \sum_{i=1}^{n} w_i = 1 \quad (1)$$

and where $v(x_1, x_2, \dots, x_n)$ is the overall value for the alternative, x_i, and w_i is the weight assigned to the *i*-th objective by the decision-makers, and $v_i(x_i)$ is the single attribute value function for that *i*-th objective.

Since this decision on the approach for program rollout would be made by multiple executive stakeholders, we used the group utility function from Keeney (2013). This approach sets up the possibility to elicit the utility curve for each stakeholder against the objectives that matter to them individually. Weights are then applied to each executive stakeholder's individual utility function to form the group utility, specifically

$$U_G(A_k) = \sum_{m=1}^{n} w_m U_m(A_k) = \sum_{m=1}^{n} w_m (\sum_{e=1}^{m_n} p_m(E_{mj}) u_m(c_{kmj}^{1}, c_{kmj}^{2}, \dots, c_{kmj}^{n_m})) \quad (2)$$

where $U_m(A_k)$ is the expected utility of member m for alternate A_k; $p_m(E_{mj})$ is the subjective probability of member m for event E_{mj}, and $u_m(c_{ame}^{o_m})$ is the utility for member m over consequence, $c_{ame}^{o_m}$, where $m = 1, \dots, n$, $e = 1, \dots, m_n$, $a = 1, \dots, k$, and $\sum_{m=1}^{n} w_m = 1$.

With the guidance of the executive stakeholders, we developed the functional forms for each of the six executive stakeholders, Operations (U_O), Branch (U_B), Fraud (U_F), Compliance (U_C), and Risk (U_R):

$$U_O(a,c,t) = [U_O(a^0,c^*,t^*) - U_O(a^0,c^*,t^0) - U_O(a^0,c^0,t^*)]U_O(c)U_O(t) + U_O(a^0,c^*,t^0)U_O(c) + U_O(a^0,c^0,t^*)U_O(t) + U_O(a^*,c^0,t^0)U_O(a)$$

$$U_B(a,c,t,b) = [U_B(a^0,c^*,t^*,b^0) - U_B(a^0,c^*,t^0,b^0) - U_B(a^0,c^0,t^*,b^0)]U_B(c)U_B(t) + U_B(a^0,c^*,t^0,b^0)U_B(c) + U_B(a^0,c^0,t^*,b^0)U_B(t) + U_B(a^*,c^0,t^0,b^0)U_B(a) + U_B(a^0,c^0,t^0,b^*)U_B(b)$$

$$U_F(v) = U_F(v)$$

$$U_C(b,v) = U_C(b^*,v^0)U_C(b) + U_C(b^0,v^*)U_C(v)$$

$$U_R(b,v) = U_R(b^*,v^0)U_R(b) + U_R(b^0,v^*)U_R(v)$$

2.3. Creating the single-dimensional utility functions

Utility functions were determined for each objective using mid-value splitting technique (Keeney and Raiffa 1976) for deterministic attributes and the certainty equivalent technique (Clemen and Reilly 2001) for uncertain attributes. This evaluation was done by proxy with the author determining the appropriate value depending on the impact to the program and company. This is an aggregation method of sorts, whereby we are driving a collective view of the value on behalf of the executive stakeholders. This layer of abstraction deviates from Keeney (2013) in that utility curves were not determined for each objective completely by each stakeholder. Instead, we used a simplifying assumption that the single utility curve was sufficient because the spread in objectives across the various stakeholders was wide, so that not every objective was of importance to every stakeholder.

Figure 3 shows the utility functions of “Additional Costs Beyond Budget” and the more straightforward value function of “Additional Time to Complete Project.” The utility function was based on conversation with the executive stakeholders and was created as a singular representation of their individual utility functions. This simplification was used in order to save the time of eliciting each individual utility function. We justify this approach based on the close similarity of each executive stakeholder in their appreciation for the utility of the various objectives.

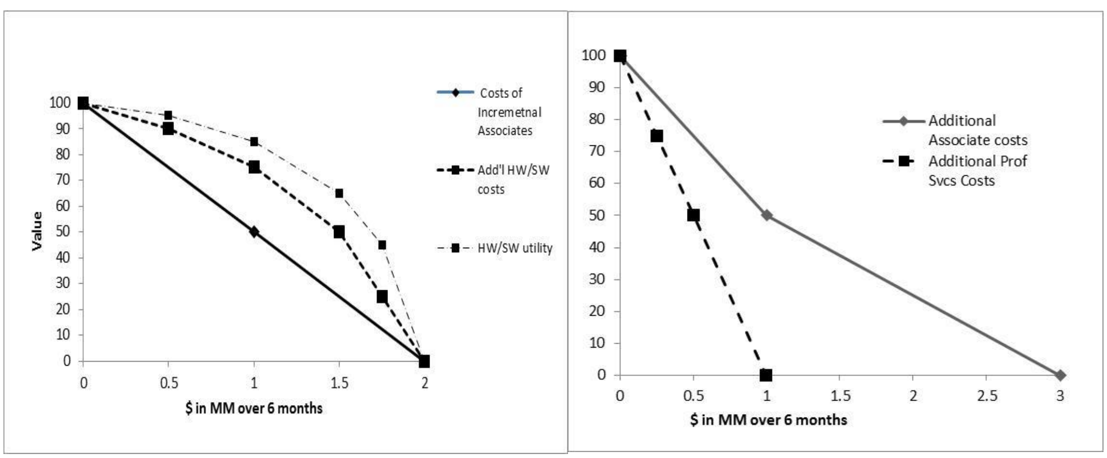


Figure 3. Examples of value and utility curves.

2.4. Determination of Alternatives

With the basic structure of the objectives and utility functions in place for the rollout decision, we then developed the alternatives that would be tested against the model. This was an active process that included both one-on-one discussions with executives as well as group discussion in our regular weekly meetings. The information gained from reference interviews with other banks that had executed similar efforts were included in the discussion, as well as the experience of others at Capital One that had seen these types of rollouts in other companies. The experience level was significant and outcomes observed by these experts varied significantly. This presented excellent context to examine the success and failure of previous rollouts. It not only drove the list of alternatives, but also acted as a check that the objectives we had chosen were relevant. Although there were many possibilities to rollout a teller system to a large branch network, the conversations with executive stakeholders settled into three categories.

1. **Big Bang:** Over a weekend shift everyone to the new systems and processes
2. **Slow Roll:** Each week rollout the changes to a small percentage of branches
3. **Regional Rollout:** Move through each region successively

Before engaging in detailed discussion, we performed a high-level review to ensure effective communication with stakeholders. This was just a simple pros-and-cons view, but relating it back to the objectives in the model, served to create a useful document for driving discussion. This process served as a primer for the executives to begin thinking about the broader impact of each alternative. The success of the scoring effort, we are convinced, was improved by keeping the process inside a framework familiar to the executives.

Table 1. The Alternatives Considered.

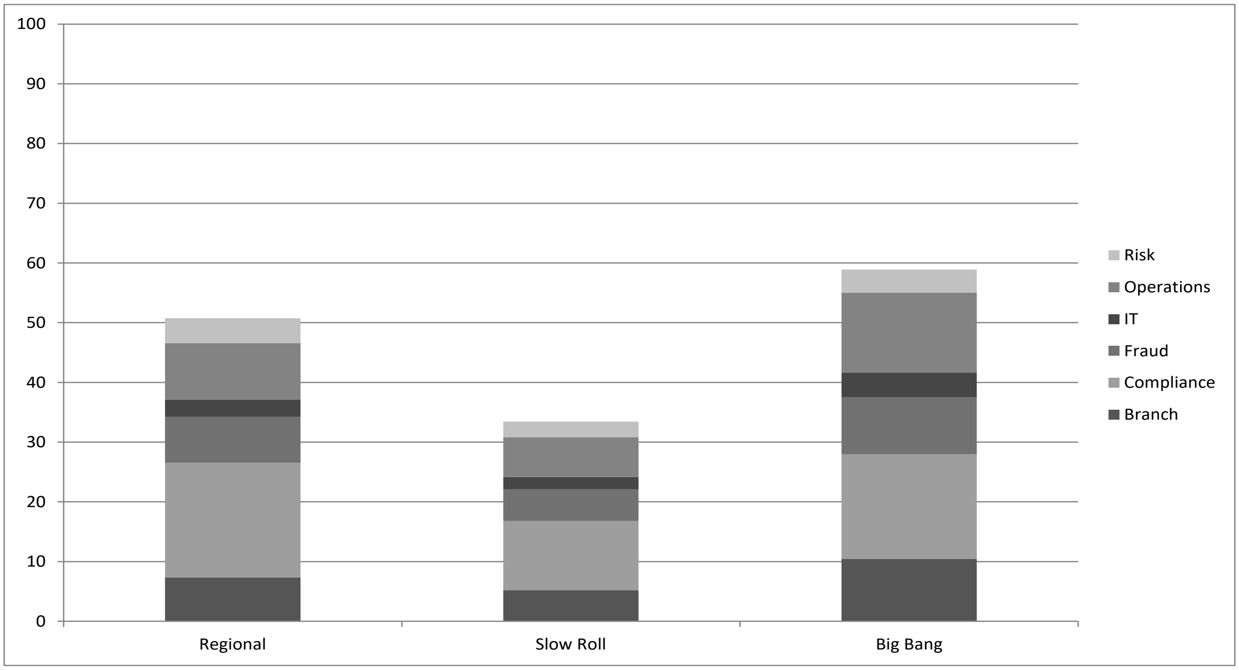
Alternatives	Approach	High-level Pros	High-Level Cons
Big-Bang	Over weekend shift all branches and operations centers simultaneously	Fastest completion Flexibility of date	No room for error correction/learning Training time tight
Slow Roll	Each week roll out a small (<5%) percentage of branches	More time to learn from mistakes Balances training load	Cannot adjust systems or repair software issues without retraining
Regional Rollout	Roll out by each of the regions and advance to the next after issues resolved	More controlled than Big Bang Could target troubled areas first to remove existing issues	Issues specific to regions may not show till too late Cannot adjust systems or repair software issues without retraining

2.5. Scoring the value for each objective across alternatives

The determination of the values for the quantitative measures was relatively straightforward. Analysis had already been performed on cost savings and improvements. High and low values had been determined and a “fairway” value determined as well. This allowed a straightforward inclusion in the model. The determination of the more qualitative objectives in the model again relied on a proxy approach. We determined the “fairway” value of these qualitative elements based on the feedback and conversation with the executive stakeholders. The final step was to add in the uncertainty inherent in some objectives to represent the full measure of variability. Defining uncertainty was straightforward as the program had many experienced managers and subject matter experts that had worked on programs of similar complexity. We determined the distributions based on the conversations with these experts and then added those into the model using Monte Carlo simulation.

2.6. Conducting utility gap assessment

Figure 4 shows the group utility for the three alternatives for program rollout, showing that the Big Bang alternative achieved the highest utility value. The stacked bar chart view in Figure 4 shows the additive components of the group utility function, allowing the decomposition of the group utility values by component objectives and by stakeholder groups.



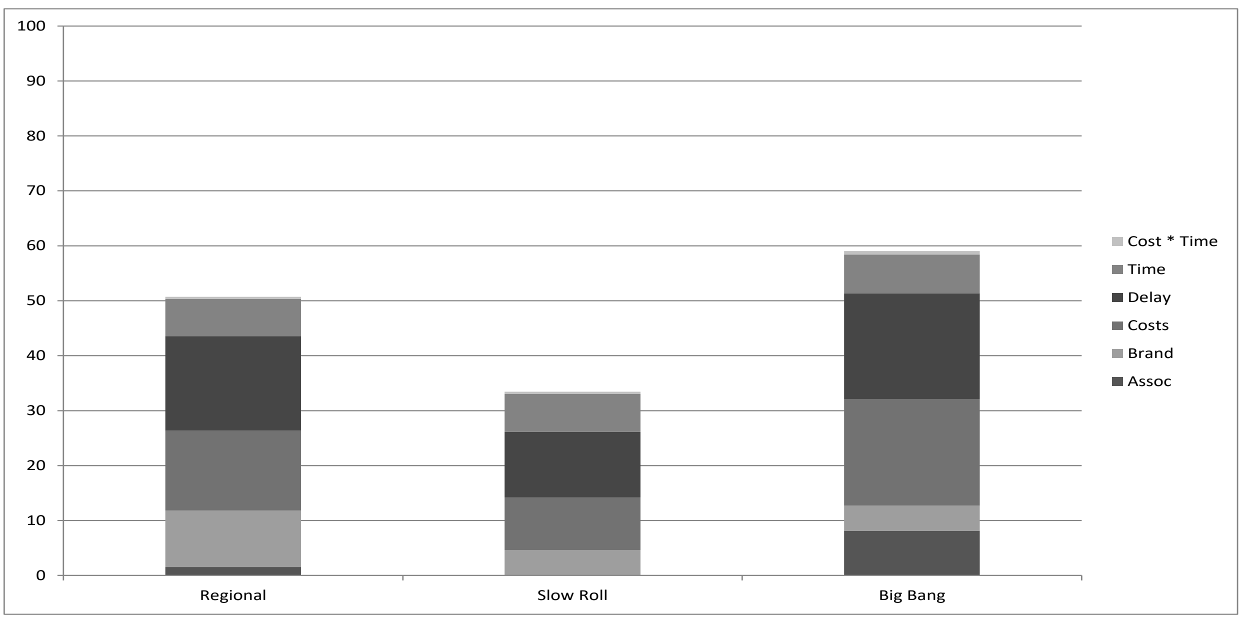


Figure 4. The utility of each alternative decomposed by stakeholder (upper) and objective (lower).

Following Merrick (2005) we conducted a utility gap assessment. This is a process of assessing the possible maximum utility for an objective versus the actual utility for the objective under a given alternative. This provides a comparison for the various alternatives, as well as indicating where each alternative fell short. A breakdown of the three alternatives into the five primary component objectives showed the specifics as to where the value was most lacking and where it was closer to realizing the full possible value. This was a typical gap analysis performed in Merrick (2005) and Feng and Keller (2006). However, the form of the group utility function also allowed us to perform utility gap analysis for each stakeholder's contribution to the group utility function. Figure 5 shows the three alternatives decomposed by objective and decomposed by stakeholder.

In this breakdown, it was clear the *Big Bang* was the superior alternative in all objectives except for "Brand." The riskier nature of a rollout occurring all at once with so much new functionality increased the effects of errors which would negatively impact the brand. This highlighted for the executive stakeholders the importance of "Brand" as one of the measures and led to the search of a fourth alternative that might combine the best of the first three alternatives and increase the overall score.

Through this analysis the stakeholders recognized that the initial set of alternatives was not sufficient. This was an important insight that came from this process of looking at rollout alternatives. Seeing that the three alternatives did not handle the concerns of all the executive stakeholders well enough, the search for a fourth better alternative was more clearly needed.

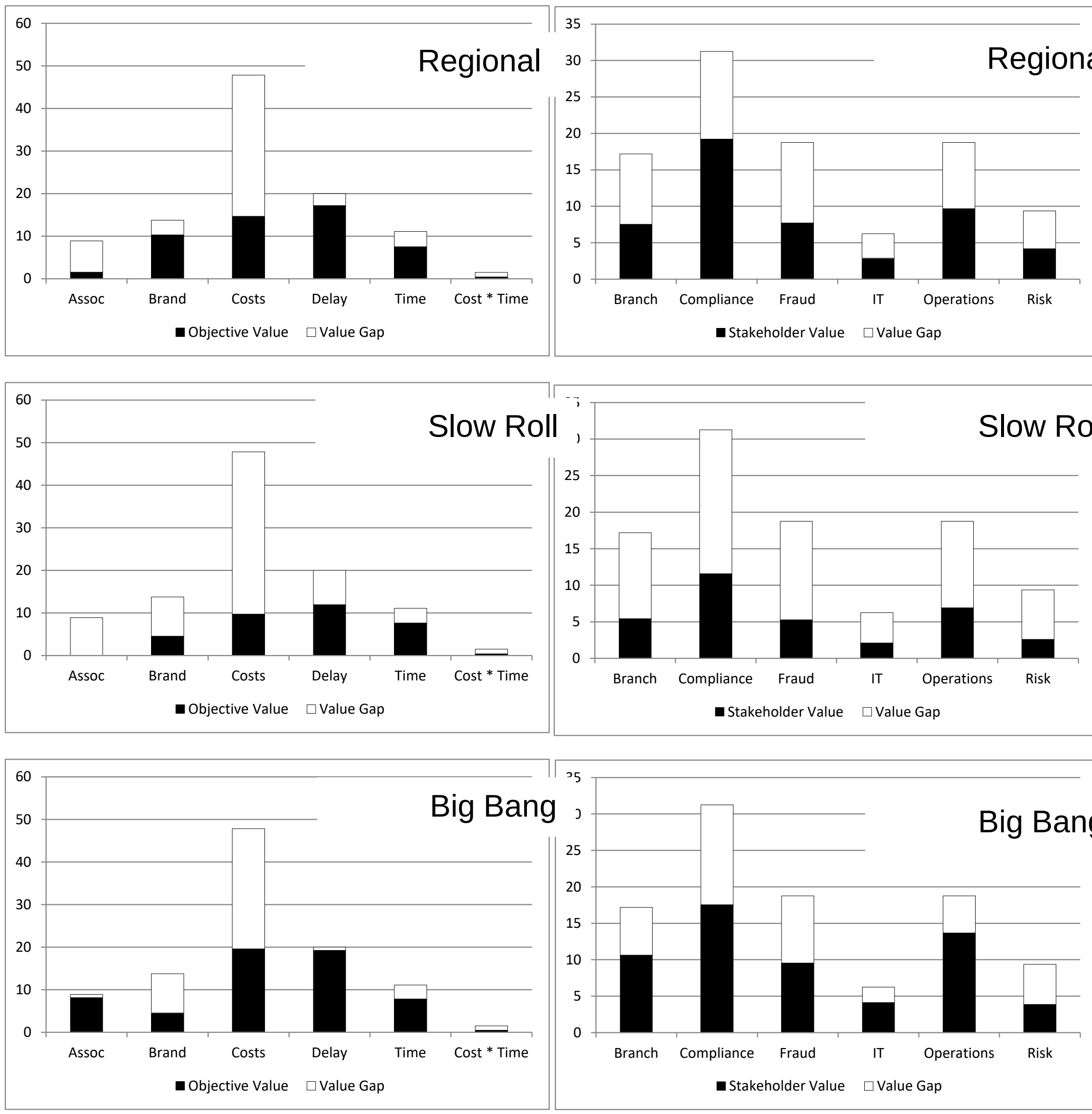


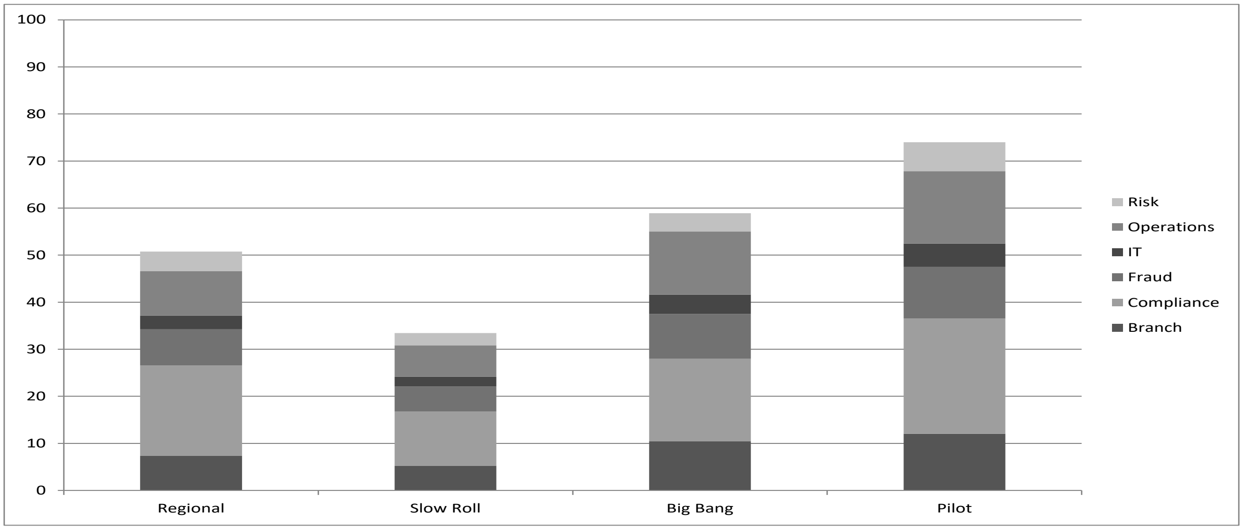
Figure 5. Utility gaps for each alternative by objective and each stakeholder.

With much of the uncertainty coming from the speed of the rollout it became clear that a slower, more careful rollout at the beginning was warranted, but a problem remained: translating a complex analytical model into a useful conversation with time-constrained executive stakeholders. The key to driving a useful conversation was a review of previous similar programs at Capital One and their outcomes across the five main objectives for this program. A lesson's learned style review is common, so this presented a comfortable approach to understanding how to proceed, but delivered in a different framework, namely the five main objectives and a means-to-ends style of analysis. Although the model itself was not explicitly shared with the executives, it did prove to be an insightful tool as it drove the analysis team's facilitation. In this manner, the discussion was richer with more grounded analysis and led to comfort in the final decision, the *Pilot then Rollout* approach.

The *Pilot and Rollout* alternative provided the best closing of the value gap. In particular, the value to "Compliance" increased tremendously as the risk of failures in the processing of customer transactions was better managed through the normal "test-and-learn" approach of a pilot. In the previous three alternatives, there were tradeoffs made between high scores in "Associate" and "Brand," but with this fourth alternative both of those objectives have high scores. This makes the overall utility for *Pilot and Rollout* the highest of the four alternatives (see Figure 6).

2.7. The Implementation

Although the implementation approach was determined, the implementation itself was a complex process that required significant oversight. There were several concerns. First, not all branches were the same. There were regional differences that needed to be accounted for in determining the pace of branch conversion to the new systems and processes. We also implemented a process where a teller who had been through the rollout would go to a future branch to be with them during their rollout. This provided useful expertise at each branch but required a significant scheduling and oversight effort to minimize travel distances.



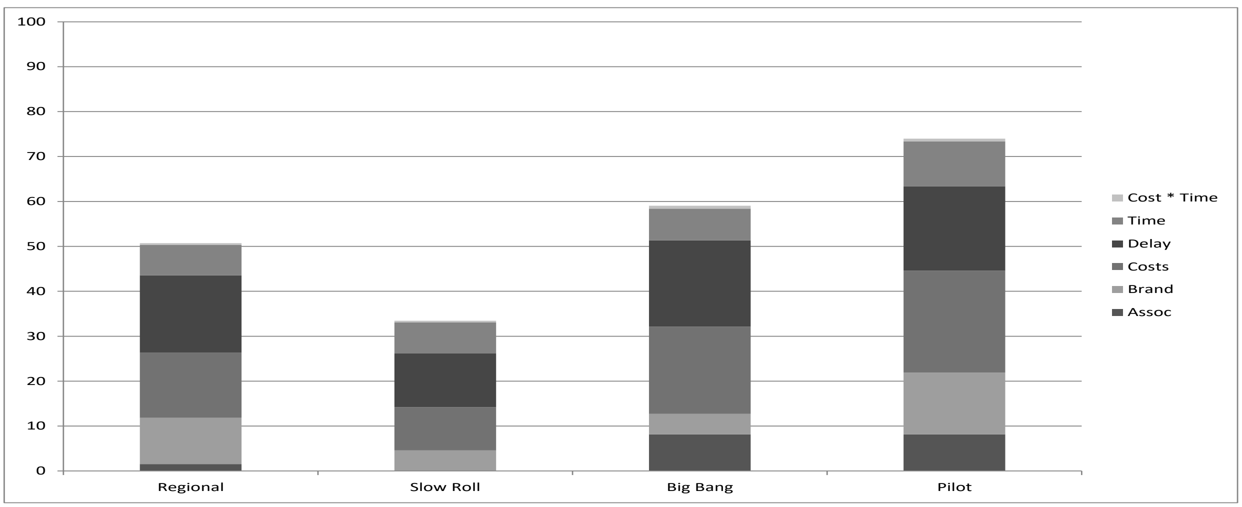


Figure 6. Utility comparison: three original alternatives and the new pilot and roll alternative.

Second, there were elements of technology and procedural changes for each rollout as the branch closed the old systems and converted to the new systems. These two parallel processes were managed by two command centers, one focused on technology and the other on the branch associates. Each of these command centers worked with their respective teams to ensure that issues were handled and appropriate schedules executed. There were dozens of steps that needed to be completed in each branch, some of which required a rollback to the old system if done improperly meaning the branch would have to be rescheduled for conversion. A third, central command center was used to coordinate across the two command centers and then into the myriad of other support teams that are part of a large banking operation. All three command centers had to work in close concert in order for the work to go smoothly and for quick issue resolution. The *Pilot and Rollout* approach allowed these teams to learn during the pilot phases and then hone their techniques as the rollout proceeded over six months.

The third concern was that all this work needed to stay invisible to the customer. As the branch opened on the following day there could be no issues in servicing customers. As the team had learned through customer feedback sessions, their expectation was that the branch would simply work and be there to handle their needs. The *Pilot and Rollout* approach allowed the command center teams to learn where the points of concern would be and how to handle them should anything go wrong. The impact was dramatic. Customers loved the changes and would frequently comment to the tellers that the upgrades were greatly appreciated.

2.8. Outcomes

The value of the *Pilot and Roll* approach was evident soon after launch of the very first branch. The initial pilot implementation was difficult. The defect rate for some of the new software was unexpectedly high and the gut-wrenchingly difficult call was made to delay by a month. Had the approach been to move forward with a quicker rollout as had been done successfully with other programs, the results would have been disastrous. In fact, in reference calls with three other banks they reported delays of six months, eight months, and for one bank a horrific delay of sixteen months. To be so forthcoming with this information was an indication of the frustration those banks had in getting to the start of their implementation. It also showed how complexity of implementation could readily turn into significant delays.

Even with this delay, the single branch pilot allowed further surprises to be better managed. As issues appeared, mitigation plans could be put in place for this single pilot that could not have been managed with a multi-branch roll out; the manual nature of the workarounds would have been too cumbersome and difficult to control. With only one branch, it was also easier to experiment with different techniques. Sometimes this resulted in a change to the software; sometimes this resulted in a change in procedure; sometimes changes, that seemed so necessary when the software requirements were elicited, were found to be unnecessary and the process and software was simplified for the future rollout. The impact of this approach was significant. From the reference calls, it was clear that other banks had struggled in implementing this very same software. Had Capital One experienced even the more moderate six-month delay, the cost overrun would have been in excess of $9M just to maintain the program. Even more time would have been spent to repair any damage done by the issues that caused the concern in the first place. A delay of sixteen-months would have been nearly $24M and surely would have had other costs associated with issues that a poor rollout would have caused. Instead, this decision process, and the new *Pilot and Rollout* alternative it revealed, avoided these costly delays as predicted in the model.

Over the next year the software development was completed in two phases and rolled out into the lone branch. This iterative process allowed for more insights and more adjustments to be used for the ultimate rollout across the entire Capital One branch network. When the rollout to other branches began, there was still trepidation amongst the executives and the program team. Now that multiple tellers would be using the system, multiple defects and issues were likely to surface. To be sure, problems did arise but they proved easier to fix and control than in previous conversions. Clearly, the reduction in risk was substantial as predicted by the strong scores of the pilot then rollout alternative for the Risk and Compliance stakeholders.

These risks can broadly be placed in three categories: Regulatory risks, Operational risks, and Reputation risks. Regulatory risks are straightforward to understand but have a low tolerance for error; as a result, Capital One was particularly keen to manage these risks tightly. With a pilot approach it was possible to closely monitor the transactions moving through the system in real time. This was critical to ensuring that all regulatory requirements were met. If there was an issue, this level of monitoring allowed for quick reaction to fix the problem. As a result, there were no regulatory issues with the *pilot and rollout* approach. This level of monitoring would not have been possible and it was through the decision approach taken that this came to light. Similarly, Operational risks were also easily monitored. The team implemented a balanced score card that grew out of the decision model based on the notion that anything worth measuring to make a decision was likely worth measuring through the rollout. This proved to be true as operational issues popped up and were again easily handled as the team monitored transactions as they began at the teller line all the way through to transmittal outside Capital One and posting to the general ledger. This level of scrutiny would not have been possible in the other approaches.

Reputation risk turned out to be a surprise. Given that the purpose of the processes and systems implemented was largely transactional, the expectation as that there would be no reputational upside and only risk to be managed. This was not true. Because of the highly scrutinized manner in which the pilot was conducted, customers found the changes to be highly positive. This was shown in the regular survey of customer satisfaction with their experience in the Branches. The survey participants are selected via a random sample and queried within days of their visit to the branch. In the immediate months after the rollout to a branch scores improves from 1 to 4 percentage points depending on the specific branch. This is a large improvement especially given that many of these branches had maintained very strong scores for years. Achieving a bump up in rating to that significance was a positive surprise. In the comments, customers said that they saw the extra care that Capital One was putting into the rollout and felt good about that experience. This had not been the result in previous rollouts. The team learned from this impact and pulled together a higher-touch rollout approach across all of the branches which centered on placing tellers, experienced in the new system, into branches that were going through the rollout.

2.9. Stakeholder Reactions

For the Executive Stakeholders, the results of this approach were astounding. Given the complex nature of the implementation and the amount of change introduced into the bank, there were expectations that significant problems would arise. Several expected there to be delays in the rollout schedule. In fact, plans were made to handle as much as a six-month delay given experience with other programs of similar magnitude. That delay did not happen. Preparations were made to handle fallout that might come from significant issues in processing transactions. That did not happen. Perhaps most surprisingly, executive stakeholders from across the bank were expecting there to be morale issues with associates as fatigue kicked in and issues with customers might arise. Certainly, the delivery team began to tire under the weight of the work, but engagement scores, a measure of associate happiness at work, actually rose during this period. These scores are measured by survey on a quarterly basis. During the time that the rollout was underway the scores moved up 3 percentage points. This was quite unexpected but because of its significance the approach the team took became a beacon for how such programs should be managed.

For some groups like Compliance and Risk Management, this approach provided a complete reversal of their usual role. Instead of being in the position of having to say "no" to requests, they became an integral part of the decision process. Their needs were imbedded in the decision model. In the very next effort at in the bank, those executives started the process asking for the same level of input. In just a few short months, the positive results are already being repeated in another important effort for the bank.

2.10. Program Conclusion

The program became a beacon for well-disciplined and nuanced risk management and decision-making at Capital One. The president of the bank declared that the program was a model for how large change efforts should be managed. The impact to the business was immediate and substantial. Costs were reduced at each branch transitioned to the new system and processes. Branch managers lauded the rollout process and how well-managed and controlled it was. Amazingly customer satisfaction ticked up a couple of percentage points, an unprecedented increase for such a large change.

Interestingly, the case for a *Pilot and Rollout* approach to large program implementation remained unobvious as other programs took different tacks. This indicates that the *Pilot and Rollout* approach was not a universally appropriate technique that the team simply struggled to discover. Instead, it was clear that each program is different and a separate decision process was warranted for each. An analysis that captured both the quantitative elements and the softer ones was pivotal to the success of the effort. It was also evident that the explicit inclusion of stakeholders in the structured decision-making process was necessary and the conversations required to construct a multi-objective, multi-stakeholder utility model meant a better examination of the potential consequences and improved alignment of the stakeholders. Although Capital One has created successful implementations of complex initiatives, these techniques provided an improvement to the processes already in place.

2.11. Contributions from this Practical Approach

During the early stages of the project, the executives were unwilling to discuss the importance of each objective to their business area in front of the group due to concerns that others would use this information against them. The decision-making process we followed involved the executives in deeper discussions about objectives than previous projects at the company and the sharing of data and information to help build the probability distributions on each attribute. This process improved trust amongst the executives and led them to share the weights they would place on each objective.

The executives quickly realized that the business areas placed very different emphasis on the objectives and would be affected very differently by the alternative implementations of this new technology. In most implementations of multi-attribute utility theory, weights on the objectives are elicited from each stakeholder and the average for each objective across the stakeholders is used in the final utility function. In the approach described in this chapter, we constructed a utility function for executive's business area and then weighted the business areas to form the company's group utility function. This allowed the executives to see how their peers would be impacted by each alternative as well as the overall impact on the company.

The resulting utility gap analysis was eye-opening and led the executives to develop a new alternative that would not have such negative impacts on one or more business areas. This implementation reveals two critical observations that are often over-looked in discussions about decision theory. First, the process of constructing a decision analysis model can have significant positive benefits in building trust and understanding amongst the stakeholders. Second, the value of decision analysis is more than just selecting an alternative; the executives developed a better alternative that would not have been considered without this analysis and it led to a significant return on investment.

Chapter 3. The Cost of Non-Cooperative Group Decision Making

When a group or committee must make a decision, the members of the group may not agree on the merits of each proposed alternative. They may measure success differently or they may have different beliefs about the probability of possible outcomes (Gilboa, Samet, & Schmeidler, 2004; Mongin, 1995, 1998; Seidenfeld, Kadane, & Schervish, 1989). Disagreements about probabilities are often caused by asymmetries in the information each group member has available (Clemen & Winkler, 1987; Winkler, 1981), and can be reduced by sharing or aggregating this information (Brodbeck, Kerschreiter, Mojzisch, & Schulz-Hardt, 2007). Different measures of success can be caused by individuals assigning different utilities to given levels of a single consequence measure (Dyer & Sarin, 1979), different consequence measures (Keeney, 2013), or different weighting of multiple objectives (Baucells & Sarin, 2003). A frequent assumption of work in group decision-making is that the group is selecting a single alternative from a common set of alternatives. This is usually the case in a cooperative group decision. However, strategic decision-making can be more complex as it is a process comprised of many individual decisions (Fredrickson & Mitchell, 1984; Papadakis, Lioukas, & Chambers, 1998) with the hope that the overall strategy is aligned (Iaquinto & Fredrickson, 1997).

In a review of the strategic decision-making literature, Eisenhardt and Zbaracki (1992) conclude “that organizations are accurately portrayed as political systems in which strategic decision-makers have partially conflicting objectives." It seems clear that the individual decision-maker plays an important role in the strategy process (Hutzschenreuter & Kleindienst, 2006). Furthermore, several studies show that organizational outcomes are improved by dissent and structured conflict (De Dreu & West, 2001; Dooley & Fryxell, 1999; Dooley, Fryxell, & Judge, 2000; Priem, Harrison, & Muir, 1995) and including decision-makers with diverse experience (Horwitz & Horwitz, 2007) and roles in the organization (Simons, Pelled, & Smith, 1999). However, political maneuverings and conflict between decision-maker groups can derail a strategic decision process (Cooper & Zmud, 1990), often caused by an asymmetry of values and objectives across the decision-makers (Kim & Kankanhalli, 2009; Leidner & Kayworth, 2006; Levine & Rossmoore, 1993).

This section extends the multiple-objective multi-stakeholder decision framework to allow for different sets of alternatives for each decision-maker and models the strategic interaction of these decisions using a game theoretic approach. Our framework assumes that the decision-makers have multiple, common objectives that are aggregated through their individual multi-attribute utility function. The outcomes for each decision-maker are affected by the choices of the other decision-makers and this effect can be different for each objective and each decision-maker can assign different weights to the objectives. The resulting utilities are a game in the sense of Von Neumann and Morgenstern (1944) and Nash (1951). A game theory construct allows us to study the equilibrium solutions when there is an asymmetry of values and objectives. We are not the first to study games with vector payoffs (Morgan, 2005; Zeleny, 1975; Zhao, 1991), but our focus is not the existence of an equilibrium. Instead, we study the impact of Cooperative and Non-Cooperative approaches to group decision-making when individual decision-makers have their own alternative sets and there is an asymmetry of values and objectives.

3.1. A Formal Framework for Group Decisions in Cooperative and Non-Cooperative Situations

Consider a set of decision-makers M, with $|M| \geq 2$. In the traditional group decision formulation, the set of alternatives A is common for all decision-makers. Each decision-maker $m \in M$ can have their own set of mutually exclusive and collectively exhaustive events that represent potential outcomes, denoted by $E_m\{E_{m,1}, \dots, E_{m,O_m}\}$, and their own consequence measure, denoted by $c_m(a) \in \mathbb{R}$ for $a \in A$. Given the usual rationality assumptions (Pratt, 1964), decision-maker m has a probability distribution over E_m with measure p_m, and a utility function $u_m\colon c_m(a) \to \mathbb{R}$ in the sense of (Von Neumann & Morgenstern, 1944).

Given a similar set of rationality assumptions at the group level, the group expected utility for alternative $a \in A$ can be written as

$$U_G(A_k) = \sum_{m=1}^{n} k_m U_m(A_k) = \sum_{m=1}^{n} k_m \left(\sum_{e=1}^{m_n} p_m(E_{me}) u_m\left(c_{me}^{o}(a)\right)\right) \qquad (3)$$

where $c_{me}^{o}(a)$ is decision-maker m's consequence under event E_{me} if they choose alternative a and k_m is the weight of decision-maker m's expected utility in the group expected utility, such that $\sum_{m \in M} k_m = 1$ (Keeney, 2013). Prior work assumed that the decision-makers shared a common set of events, so $E = E_m$ for all $m \in M$, and assumed that the group had a probability distribution formed by aggregating the individual's probability distributions and a utility function formed by aggregating the individual's utility functions. Instead, the group expected utility can be formed by aggregating the individual's expected utility (Keeney, 2013).

In the multiple objective version, decision-maker m evaluates the outcomes of the group's decision on o_p objectives, so the consequence measure becomes a vector $c_{me}(a) = (c_{me}^1(a), \dots, c_{me}^{o_m}(a))$ for decision-maker m's consequences under event E_{me} if they choose alternative a. However, one does not need to specify entirely different sets of objectives for each decision-maker. Instead one can specify a single consequence measure $c_e(a) = c_{me}(a)$ for all $m \in M$ and $a \in A$ and instead represent the preference asymmetry through the individual decision-maker's utility functions $u_m(c_{me}^1(a), \dots, c_{me}^{n_m}(a))$. For example, if the individual utility functions can be represented in the linear-additive form $u_m\big(c_{me}^1(a), \dots, c_{me}^{n_m}(a)\big) = \sum_{o=1}^{p} w_m^o \, u_m^o(c_{me}^o(a))$ where $\sum_{o=1}^{p} w_m^o = 1$ (Keeney & Raiffa, 1993), then the preference asymmetry can be represented by differences in the weights w_m^o across decision-makers.

Keeney's formulation (Keeney 2013) defines a rational group utility given a common set of alternatives. However, suppose the set of alternatives A_m is different for each decision-maker $m \in M$. If the decision-makers are collaborating, then one can simply consider all possible combinations of alternatives for each decision-maker, so $A = A_1 \times A_2 \times \dots \times A_{|M|}$. However, if the group is not collaborating, then we have a game theoretic set-up. The interesting question here is how much group utility is lost by the lack of collaboration, where group utility is defined by (3).

Let us begin our discussion of this alternative formulation of a group decision by considering the case where $|M| = 2$ and $|A_m| = 2$ for each decision-maker. Thus, we are considering the case where two decision-makers are each choosing between two different alternatives. As the alternatives chosen by each decision-maker effect the outcomes of each decision-maker on each objective, the result is a two-by-two game for each objective (see Figure 7).

Player 2

Player 1	l	r
U	$x_{1,i}(U,l)$ $x_{2,i}(U,l)$	$x_{1,i}(U,r)$ $x_{2,i}(U,r)$
D	$x_{1,i}(D,l)$ $x_{2,i}(D,l)$	$x_{1,i}(D,r)$ $x_{2,i}(D,r)$

Figure 7. Example of normal form game representing the outcomes of the possible choices by each decision-maker under the i-th objective.

We use the traditional notation for simple two-by-two games by defining $A_1 = \{U, D\}$ and $A_2 = \{l, r\}$. The two decision-makers each consider the same objectives in making their decision but can differ in the weights they assign to each objective. We consider two objectives, i.e. $n = 2$. In this approach, the outcomes of each objective under the alternatives chosen by each decision-maker can be represented as a normal form game. We then assume a linear-additive utility function for each decision- maker

$u_m\left(c_{me}^1(a_1,a_2),\ldots,c_{me}^{n_m}(a_1,a_2)\right) = \sum_{o=1}^{p} w_m^o\, u_m^o(c_{me}^o(a_1,a_2))$, where $\sum_{o=1}^{p} w_m^o = 1$. Figure 8 shows the resulting normal form game in the utilities of each decision-maker for each combination of alternatives.

		Player 2: l	Player 2: r
Player 1	U	$u_{1,U,l} = w_{1,1}u_{1,1}\left(x_{1,1}(U,l)\right) + w_{1,2}u_{1,2}\left(x_{1,2}(U,l)\right)$ $u_{2,U,l} = w_{2,1}u_{2,1}\left(x_{2,1}(U,l)\right) + w_{2,2}u_{2,2}\left(x_{2,2}(U,l)\right)$	$u_{1,U,r} = w_{1,1}u_{1,1}\left(x_{1,1}(U,r)\right) + w_{1,2}u_{1,2}\left(x_{1,2}(U,r)\right)$ $u_{2,U,r} = w_{2,1}u_1\left(x_{2,1}(U,r)\right) + w_{2,2}u_2\left(x_{2,2}(U,r)\right)$
	D	$u_{1,D,l} = w_{1,1}u_{1,1}\left(x_{1,1}(D,l)\right) + w_{1,2}u_{1,2}\left(x_{1,2}(D,l)\right)$ $u_{2,D,l} = w_{2,1}u_{2,1}\left(x_{2,1}(D,l)\right) + w_{2,2}u_{2,2}\left(x_{2,2}(D,l)\right)$	$u_{1,D,r} = w_{1,1}u_{1,1}\left(x_{1,1}(D,r)\right) + w_{1,2}u_{1,2}\left(x_{1,2}(D,r)\right)$ $u_{2,D,r} = w_{2,1}u_{2,1}\left(x_{2,1}(D,r)\right) + w_{2,2}u_{2,2}\left(x_{2,2}(D,r)\right)$

Figure 8. The normal form game considering each decision-makers two objective utility function.

The group utility of a given choice is given by

$$U_G\left((a_i,a_j)\right) = k_1\left(w_{1,1}u_{1,1}\left(x_{1,1}(a_i,a_j)\right) + w_{1,2}u_{1,2}\left(x_{1,2}(a_i,a_j)\right)\right)$$

$$+k_2\left(w_{2,1}u_{2,1}\left(x_{2,1}(a_i,a_j)\right) + w_{2,2}u_{2,2}\left(x_{2,2}(a_i,a_j)\right)\right), \quad (4)$$

where k_1 and k_2 are the group weight for the two decision-makers. It is interesting to consider the difference between optimal group utility and the group utility of a Nash equilibrium for the game in Figure 8, or the group utility lost by failing to cooperate. In the following, we will assume that k_1=$k_2 = \frac{1}{2}$.

3.2. Optimal Strategies in Collaborative and Non-Collaborative Group Decisions

This formulation suggests an interesting complexity. Suppose the outcomes for each decision-maker under the first objective reward agreement, like in a “Matching Pennies” game, while the outcomes under the second objective reward disagreement, like in a “Disharmony” game. Figure 9 shows the formation of two objectives and each decision-maker’s utility for each alternative.

The Nash equilibrium is a strategy where neither player can increase their expected utility by unilaterally deviating from the strategy. The Nash equilibrium can be a mixed strategy where each decision-maker chooses a strategy from a random distribution to obfuscate their choices or a pure strategy if there is a single alternative chosen by each decision-maker with certainty.

The Nash equilibrium is the leading solution concept for Non-Cooperative games, where the decision-makers are not collaborating. When the decision-makers do collaborate, we can consider the Keeney (2013) formulation with the enlarged set of alternatives, specifically $A = \{(U,l),(U,r),(D,l),(D,r)\}$.

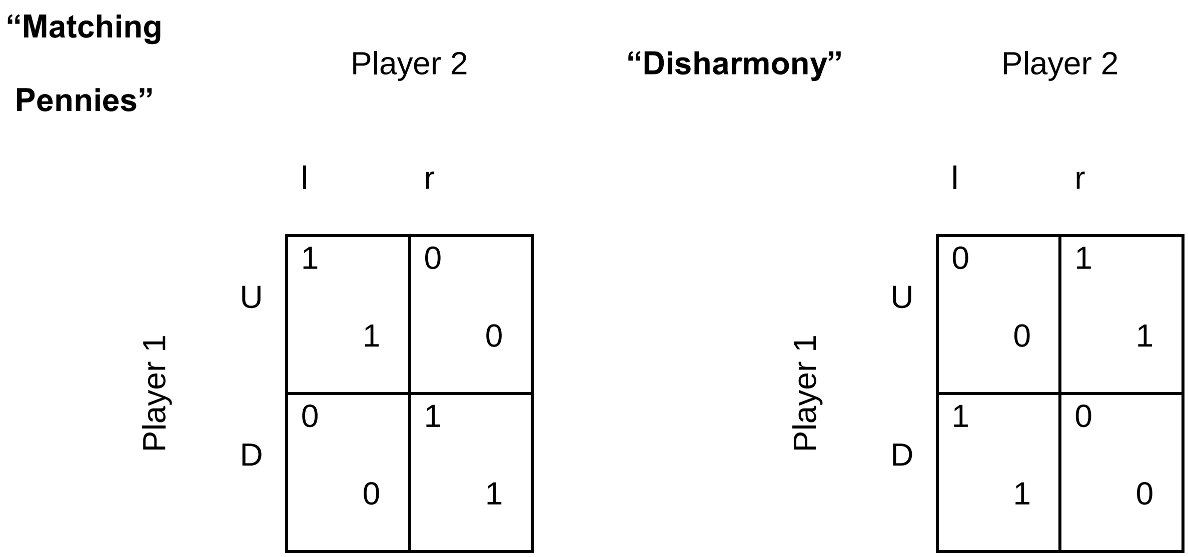


Figure 9. Example of Normal Form Game representing plays on two attributes ("Matching Pennies" and "Disharmony").

We explore the behavior of games with multiple objectives by assuming different games for each objective. We consider nine games, seven common games from the literature plus two other games that describe commonly observed strategic interactions. In Figure 4, the two games in white are the nontraditional games. They are opposites of two other games and model some expected behavior which provided some interesting results. We consider all combinations of these nine games in the formulation described in Figure 10.

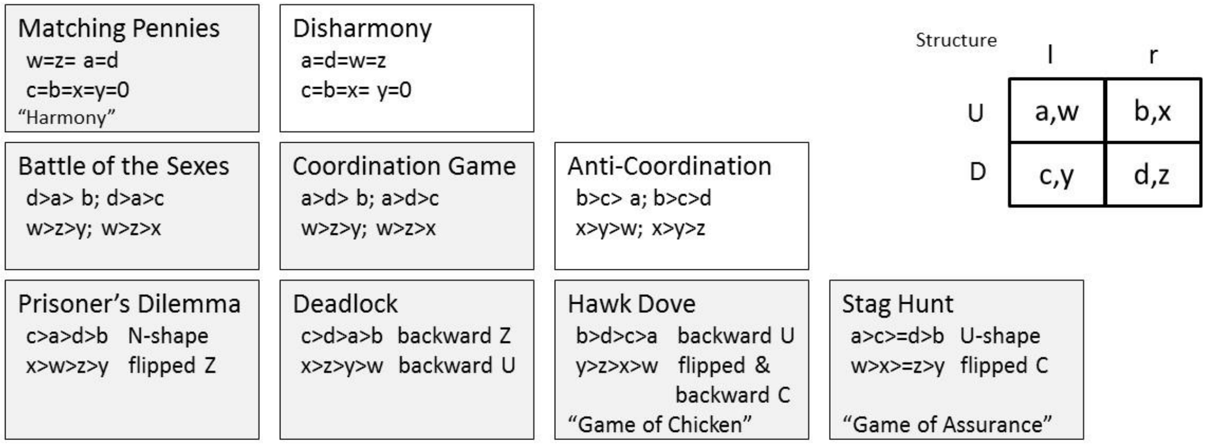


Figure 10. The seven traditional games and the two nontraditional but related games that were used to explore Non-Cooperative decision-making behavior.

3.3. An Example of Two Diners

We take inspiration from the example in Keeney (2013) to illustrate our multiple objective game theory approach for Non-Cooperative decision-making. Consider two people choosing where to go to dinner. They have two shared objectives. First, they wish to enjoy the food. Second, they wish to enjoy the ambiance. Diner 1 might focus on location and describes his alternatives as uptown and downtown. Diner 2 might focus on cuisine style and describe her alternatives as Lebanese and Russian. The utilities for the two diners for the two objectives are shown in Figure 11. We use the notation "U" for the Uptown location and "D" for the Downtown location, along with "l" for the Lebanese restaurant and "r" for the Russian restaurant.

"Enjoy the Food"

Diner 1 \ Diner 2	l	r
U	1, 1	0, 0
D	0, 0	1, 1

"Ambiance"

Diner 1 \ Diner 2	l	r
U	1, 0	1, 1
D	0, 0	0, 1

Figure 11. Example of Normal Form Game representing two objectives about going to dinner.

For this example, let's further assume that there are four restaurants, one of each type in each location. Both diners agree that the uptown Lebanese restaurant and the downtown Russian restaurant have the better food, but diner 1 likes the uptown scene no matter the restaurant whereas diner 2 prefers the ambience of Russian restaurants no matter the location. We use "Matching Pennies" to model the diners' objective to enjoy the food and construct a game, we call "Selfish", to model the diners' individual focus on ambiance.

Although we have expanded on the framing of Keeney (2013) by not constraining the alternative set to be the same for each diner, we are constraining this example to have the decision-makers (diners) share the objectives. We do this to make the example simpler. We can imagine objectives held as important by only one decision-maker (Keeney, 2013). To model this, we simply use zero payoffs for the decision-maker that does not hold this objective as important.

We can see the impact that these behaviors could have on the group decision. We can combine the two objectives in the diners' example, "Matching Pennies" and "Selfish" based on the weighting, k_m, that each diner (decision-maker) has and create a single combined game that shows all the information of the individual diners' preferences. In Figure 12's left representation, m_1 has 90% weighting on Objective 1 while m_2 has 10% weight on Objective 1. In the right representation in Figure 12, m_1 still has 90% weighting on Objective 1, but m_2 has changed her weightings so that she has 70% weight on Objective 1.

P1 90% on Obj 1

P2 10% on Obj 1

Diner 1 (m_1) \ Diner 2 (m_2)	l	r
U	1, 0.1	0.1, 0.9
D	0, 0	0.9, 1

P1 90% on Obj 1

P2 70% on Obj 1

Diner 1 (m_1) \ Diner 2 (m_2)	l	r
U	1, 0.95	0.3, 0.1
D	0, 0	0.85, 1

Figure 12. Two Examples of Normal Form Games representing the combined objectives about going to dinner.

The result is an important shift. In the right representation, there are pure strategy Nash equilibria in both (U, l), an uptown Lebanese restaurant, and (D, r), a downtown Russian restaurant, while the left representation has a pure strategy Nash equilibrium in just (D, r), a downtown Russian restaurant. Note, both have a mixed strategy Nash equilibrium as well.

We can solve for the mixed strategy equilibrium. Staying with the notation of Figure 12, we will need to introduce the probability that each decision-maker will place on a particular alternative. We use the standard game notation for these probabilities. Let p be the probability that m_1 selects alternative "U" and $(p - 1)$ the probability m_1 selects alternative "D". Let q be the probability that m_2 selects alternative "l" and $(q - 1)$ be the probability that m_2 selects alternative "r".

We stay with the solution concept from Nash (1951), and, using the utility equations from Figure 12, we can construct the mixed strategy Nash equilibrium. We set the probability of selection of an alternative weighted by the opposite decision-maker's utilities for that alternative equal to the probability of selection of the other alternate weighted by the opposite decision-maker's utilities for that alternative.

$$p(u_{2,U,l} + u_{2,U,r}) = (1 - p)(u_{2,D,l} + u_{2,D,r}), \tag{5}$$

$$q(u_{1,U,l} + u_{1,D,l}) = (1 - q)(u_{1,U,r} + u_{1,D,r}) \tag{6}$$

Solving for p and q

$$p = (u_{2,D,r} - u_{2,U,r})/(u_{2,U,l} + u_{2,U,r} - u_{2,D,l} - u_{2,D,r}), \tag{7}$$

$$q = (u_{1,D,r} - u_{1,U,r})/(u_{1,U,l} + u_{1,U,r} - u_{1D,l} - u_{1,D,r}), \quad (8)$$

With these formulations, we can calculate the probability that each decision-maker would have for each alternative when a pure strategy solution is not present and a mixed strategy solution must be used. Interpreting the left representation is straight forward because of the single Nash equilibrium. No matter what the decision-maker weighting, k_m, is between the two diners for the final group answer, (D, r) will be the alternative chosen since this is the equilibrium for each diner. That is not true for the right representation. Since there are two Nash equilibria, (U, l) and (D, r), depending on how the diners "solve" the game, they can get stuck on an inferior alternative. In Figure 13, we see the behavior of group utility loss possible in some combinations of decision-makers' weightings on objectives. We further explore this notion of group utility loss in the examples below.

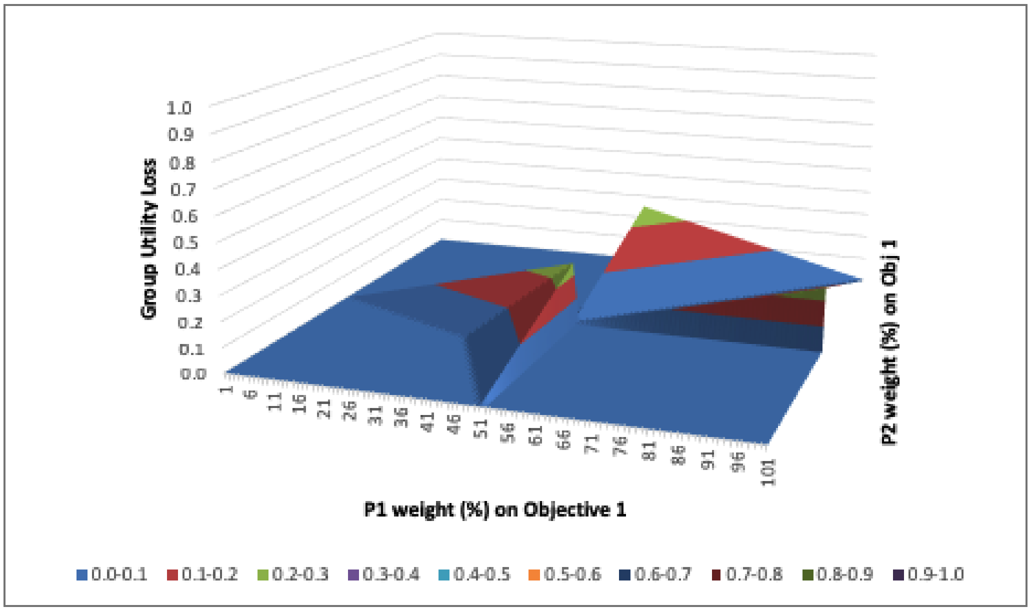


Figure 13. Regions of Group Utility Lost in Non-Cooperative Decision-Making for two diners going to dinner.

3.4. Non-Cooperative Decision-Making

To explore the behavior of the differences between the Nash equilibria and optimal group utility, we create surface plots of the two decision-makers' weightings on Objective 1, as we did with the example of the two diners in Figure 12, with the height of the surface plot indicating the difference between the Nash equilibria and the optimal group utility. In addition to this surface plot, we provide a map of the quadrants in which the pure strategy equilibria appear, to better understand the behavior of this group decision model.

We can explore the impact of various combinations of standard games to see what their behaviors are and what the implications are. The seven standard games plus the two added games make for thirty-six unique pairings. We illustrate some of this group's behavior with a few of these pairings:

1. "Matching Pennies" and "Coordination"
2. "Battle of the Sexes" and "Coordination"
3. "Battle of the Sexes" and "Anti-Coordination"
4. "Coordination" and "Hawk-Dove"
5. "Deadlock" and "Hawk-Dove"

Imagine that m_1, the Manufacturing decision-maker, and m_2, the Product Management decision-maker, have two objectives in common such that Objective 1, "Matching Pennies", represents *"Cost to Manufacture"* and Objective 2, "Coordination", represents *"Quality" (Figure 14).* For m_1, Manufacturing, the "U" alternative represents "Internal, Custom, Higher-Quality" and the "D" alternative represents "Outsourced, Mass-Production, Lower-Quality”. For m_2, Product Management, “l” represents “Many Features” and “r” represents “Limited Features”. For Objective 1, *“Cost to Manufacture”,* the decision-makers get utility only on (U, l) and (D, r). For Objective 2, “*Quality”,* the situation is more complex. The decision-makers wish to coordinate but have a clear ordering of alternative pair preferences with a many featured, internally custom-made, product at the highest level of utility, and an outsourced, mass manufacture, limited feature product at the lowest level of utility.

Cost to Manufacture

Player 1 (m_1) \ Player 2 (m_2)	l	r
U	1, 1	0, 0
D	0, 0	1, 1

Quality

Player 1 (m_1) \ Player 2 (m_2)	l	r
U	1, 1	0.25, 0.25
D	0.5, 0.5	0.75, 0.75

Figure 14. Example of two objectives modeled as “Matching Pennies” and “Coordination”.

As we see in Figures 15 and 16 there are weightings where the two decision-makers can rationally land on a Nash equilibrium and lose some of the available optimal group utility.

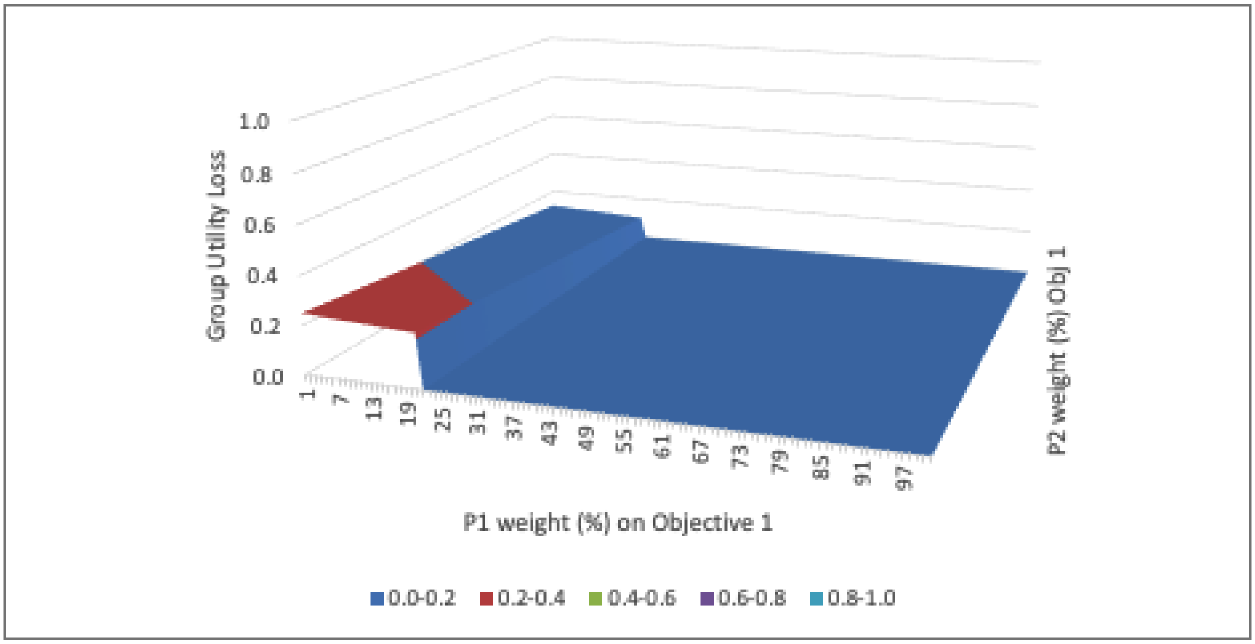


Figure 15. Regions of Group Utility Lost in Non-Cooperative Decision-Making for "Matching Pennies" versus "Coordination".

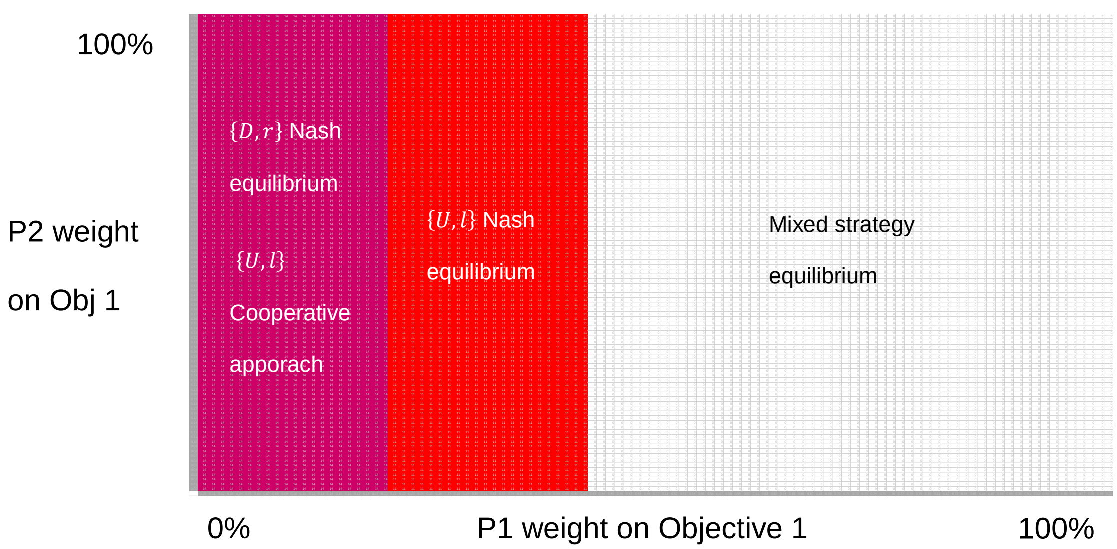


Figure 16. Regions of Pure Strategy Equilibria for "Matching Pennies" versus "Coordination".

In the example with “Matching Pennies” and “Coordination” as the two games used to model objectives, Figure 14 shows the objectives described as two normal-form games. The payoffs are all scaled from 0 to 1. Figure 15 shows the difference between the pure strategy Nash equilibria and the optimal group utility. This is a representation of the loss that the pair of decision-makers will have if they approach the decision as a Non-Cooperative process. Where there is no loss, there is either only one pure strategy equilibrium, or only a mixed strategy equilibrium. In these cases, there is no difference between the Non-Cooperative (game theoretic) and Cooperative (Keeney 2013) approaches.

Although Figure 15 (and the others like it) does not give a complete view of the behavior, it is enough to show that there is the possibility of loss with a Non-Cooperative approach to group decision-making. Figure 16 explains more of the behavior by showing the location by quadrant of the equilibria. Note that this example shows the presence of both the single Nash equilibrium and the mixed-strategy equilibrium. These correspond with the blue area on Figure 15indicating that there is no loss of group utility. It is only the region where m_1 weights Objective 1 between 0% and 20% that there will be any group utility loss.

This provides some insight into the underlying behavior of this group decision model and the changes that will occur, not only in the loss of group utility (Cost of Conflict), but also in the alternative set that is chosen depending on the weighting of the objectives by the decision-makers.

Employee Engagement

Player 2 (m_2)

Player 1 (m_1)	l	r
U	1 0.5	0 0
D	0 0	0.5 1

Quality

Player 2 (m_2)

Player 1 (m_1)	l	r
U	1 1	0.25 0.25
D	0.5 0.5	0.75 0.75

Figure 17. Example of two objectives modeled as "Battle of the Sexes" and "Coordination".

For the example shown in Figure 17, we continue with the two decision-makers, m_1, Manufacturing, and m_2, Product Management. We also keep Objective 2, "Coordination", to represent *"Quality",* but now we change Objective 1 to "Battle of the Sexes" as a representation of *"Employee Engagement".* We can think of this as "Manufacturing" preferring to make high quality, many featured products with their skilled workers but accepting that limited feature products are better made by mass market techniques. For "Product Management", the move to mass market production could be how they see their engagement in the future, but they accept that there is some value in many featured, custom products. Neither group sees employee engagement in many featured, mass-made products or limited feature, custom-made products.

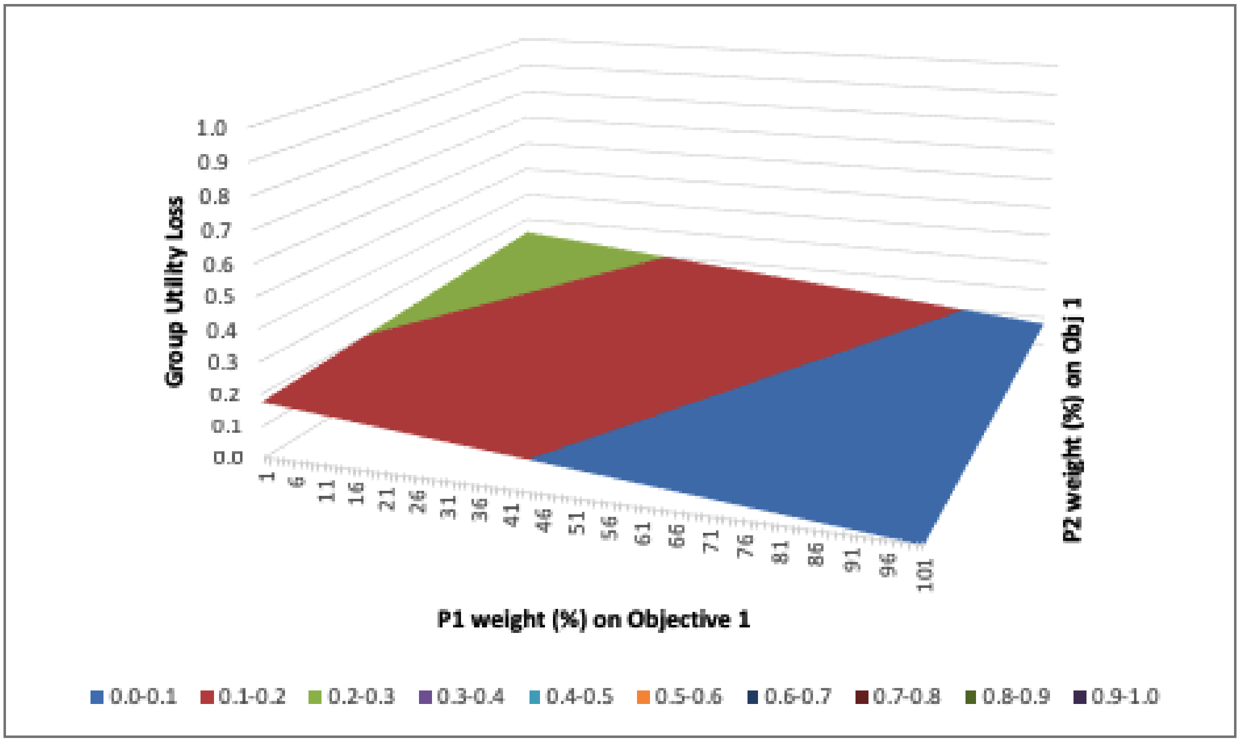


Figure 18. Regions of Group Utility Lost in Non-Cooperative Decision-Making for "Battle of the Sexes" and "Coordination".

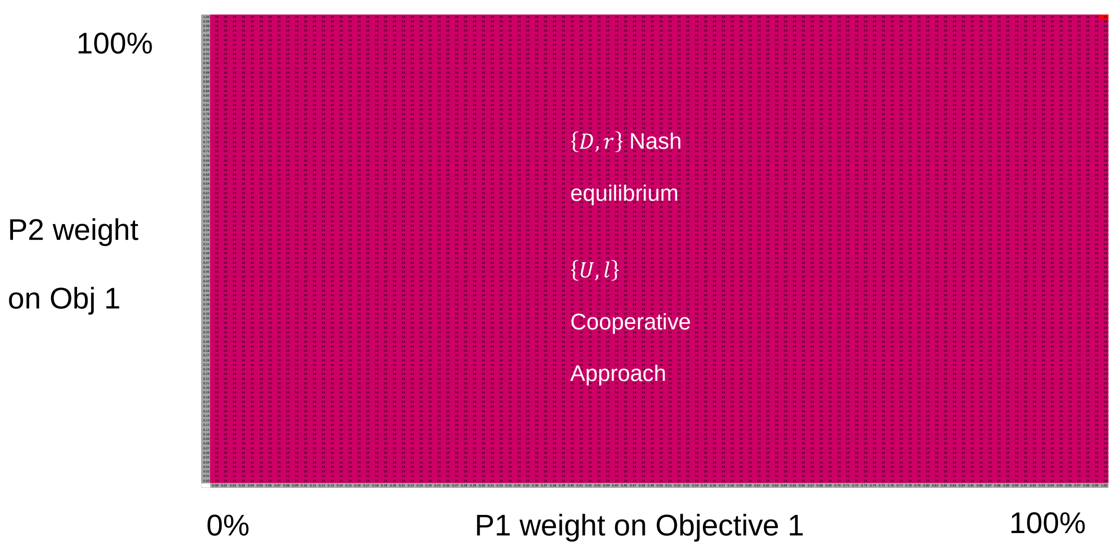


Figure 19. Regions of Pure Strategy Equilibria for "Battle of the Sexes" and "Coordination".

In Figure 15 with “Matching Pennies” and “Coordination” as the two objective models, we see that m_1 controls the location of the interesting behavior while m_2 contributes only to the magnitude of impact that a Non-Cooperative decision-making process will have. Contrast the example in Figure 15 with Figure 18 “Battle of the Sexes” and “Coordination” as the two objective models, where both $m_1$and m_2 have influence throughout the weighting space for the objectives. The change from an objective with half of the payoffs as zero, but spread to all four quadrants, for one that also has half the payoffs as zero, but concentrated in two quadrants changes the behavior, so that now the influence is across the entire weighting space. Additionally, altering the third payoff amount in “Battle of the Sexes”, 0.5, to be closer to 1 or closer to 0, changes the elevation of the plane but not the general form. It is the structure of the objectives (games) in terms of the payoff ordering that is influential here. Later in the paper, we will see that the variety and magnitude of the payoffs contribute to the variety and magnitude of the difference between the Nash equilibria and the optimal group equilibrium.

Pairing “Anti-Coordination” with “Coordination”, as in Figure 17, generates yet another behavior. As seen in Figure 18, the region of interest is now symmetrical with mixed strategy equilibria creating the flat plane areas as in the “Matching Pennies” and “Coordination” example but also two symmetrical areas of sloping difference between the Nash equilibrium and the optimal group utility. This makes for an interesting point around the region where both decision-makers weight the two objectives equally, $k_1 = k_2 = \frac{1}{2}$. Small changes in those weightings will change the optimal group and Nash equilibria alternatives. Since this is a trough, the amount of group loss will not be significant but the variety of alternatives with such small changes is of interest.

The driver for this behavior is the symmetrical nature of the two alternatives. The combined normal form, after the two objectives have been brought together, is in the same form as the "Prisoner's Dilemma" game with an optimal value for m_1 and m_2 (without reference to the group utility) but a construct of the game (combined objectives) that will lead them to the inferior choice. This is true irrespective of the weighting between the two decision-makers. Other combinations of the games modeled as objectives generated this behavior suggesting a class of combinations that should be considered in the same light as the solution to "Prisoner's Dilemma".

Cost

Player 1 (m_1) \ Player 2 (m_2)	l	r
U	0.25, 0.25	1, 1
D	0.75, 0.75	0.5, 0.5

Quality

Player 1 (m_1) \ Player 2 (m_2)	l	r
U	1, 1	0.25, 0.25
D	0.5, 0.5	0.75, 0.75

Figure 20. Example of two objectives modeled as "Coordination" and "Anti-Coordination".

For the example in Figure 20, we keep Objective 2, “Coordination”, to represent *“Quality”* but now bring in an opposing structure for Objective 1, “Anti-Coordination”” to represent *“Cost”.*

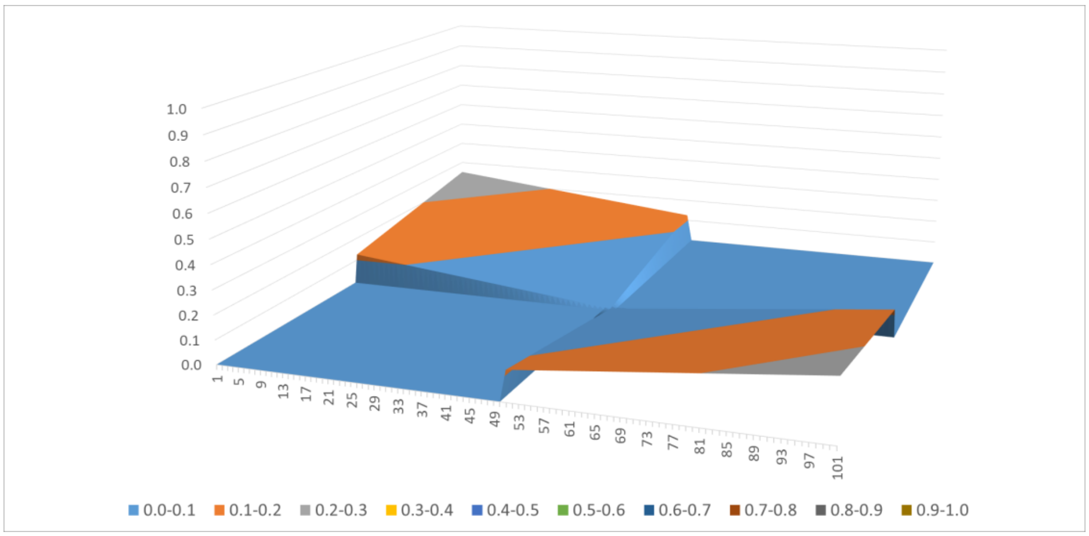


Figure 21. Regions of Group Utility Lost in Non-Cooperative Decision-Making for “Coordination” and “Anti-Coordination”.

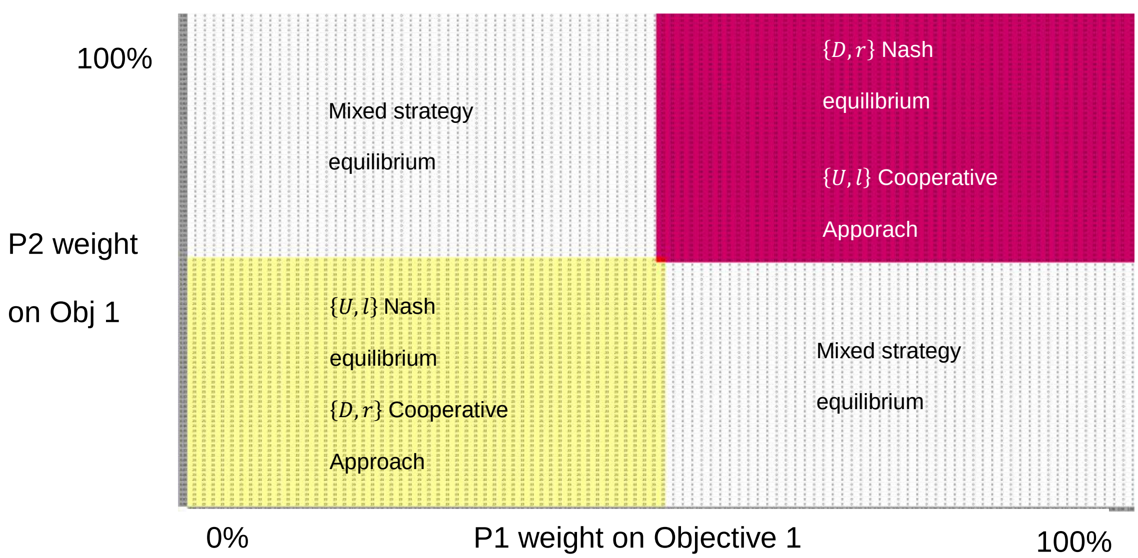


Figure 22. Regions of Pure Strategy Equilibria for “Coordination” and “Anti-Coordination”.

The three previous examples were all combinations with the “Coordination” and “Anti-Coordination” games as one of the objectives. This was useful in showing the variety of behavior of relatively simple games as the models for the objectives. The following examples use games with more payoffs across the four quadrants.

Coordination

		Player 2 m_2	
		l	r
Player 1 m_1	U	1, 1	0.25, 0.25
	D	0.75, 0.75	0.75, 0.75

Hawk-Dove

		Player 2 m_2	
		l	r
Player 1 m_1	U	0, 0	1, 0.25
	D	1, 0.75	0.5, 0.5

Figure 23. Example of two objectives modeled as “Coordination” and “Hawk-Dove”.

Figure 23 shows an example with a coordination game for one objective and hawk-dove for the other. As we can see in Figure 24, having payoffs, in all four quadrants for both games, generates more interesting behavior. In this example, the variety of behavior has increased. All the combinations using “Hawk-Dove” as an objective produce a saddle-like behavior which can be seen in Figure 24. Additionally, Figure 25 shows that there are considerable differences in the Nash equilibrium alternative and the optimal group alternative as the weightings, that the decision-makers place on the objectives, change. These changes are attributable to having two objectives with multiple possible payoffs across all four quadrants.

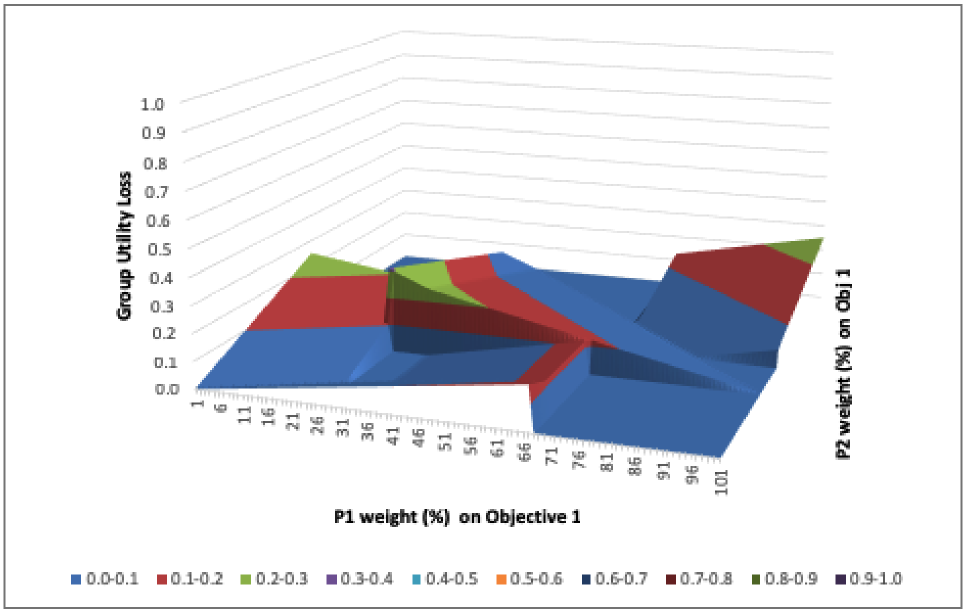


Figure 24. Regions of Group Utility Lost in Non-Cooperative Decision-Making for "Coordination" and "Hawk-Dove".

This variety creates two things. First, as in the examples of Figures 14 and 20, there is enough variety that there are payoff combinations that create mixed strategy only solutions. Second, again because of the variety of payoffs, there are regimes where the payoffs come together to generate more than one Nash equilibria and with that a greater difference with the optimal group utility. The peaks that are shown in Figure 24 indicate differences that are greater than any of the other examples. Across all the combinations, "Hawk-Dove" and the other more complex games generated areas of greater difference than those of “Matching Pennies”, “Harmony”, and “Battle of the Sexes” which have more zero payoffs and less differentiated payoff values. Thus, there was less difference in the Nash equilibrium and the Optimal group utility.

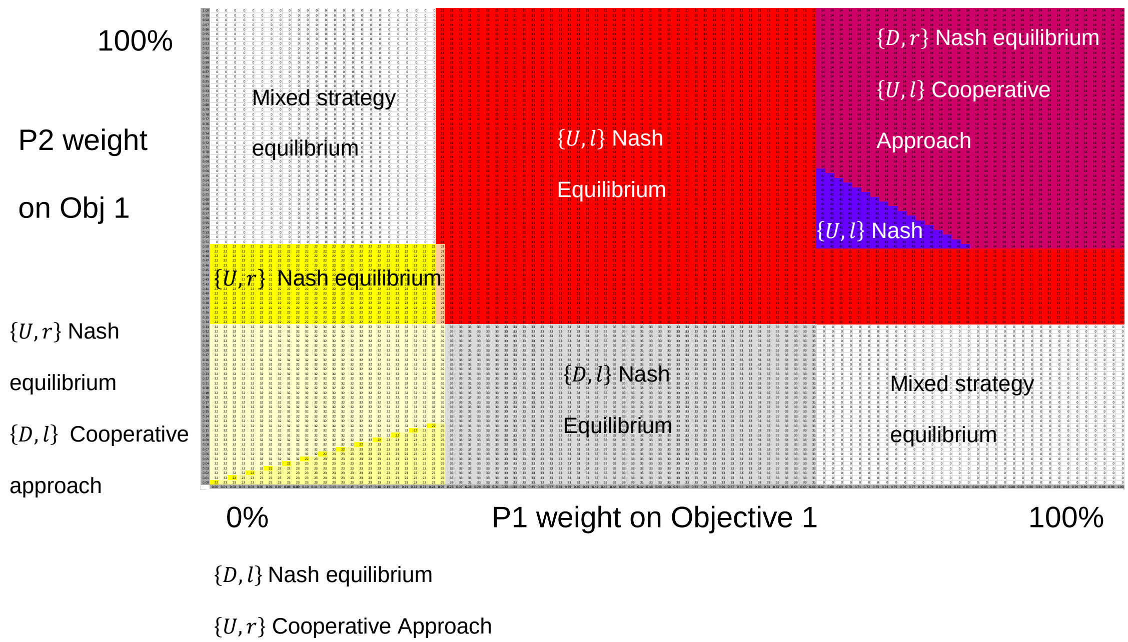


Figure 25. Regions of Pure Strategy Equilibria for “Coordination” and “Hawk-Dove”.

Finally, we see different behavior with other combinations as in Figure 26. In this example, we see the greatest amount of group utility loss in the objective combinations as well as the characteristic trough of “Hawk-Dove”. Since “Deadlock” has an equilibrium as part of its structure, the effect is to create both symmetry in the group utility loss surface plot and to increase the magnitude of the group utility loss at the peak. This behavior for “Deadlock” appears throughout its other combinations as well.

The equilibrium inherent in the "Deadlock" objective also has the influence of reducing the change in alternatives as the weightings of the decision-makers change.

Deadlock

Player 2 m_2

Player 1 m_1		r
U	0.25 / 0.25	0 / 1
D	1 / 0	0.5 / 0.5

Hawk-Dove

Player 2 m_2

Player 1 m_1	l	r
U	0 / 0	1 / 0.25
D	0.25 / 1	0.5 / 0.5

Figure 26. Example of two objectives modeled as "Deadlock" and "Hawk-Dove".

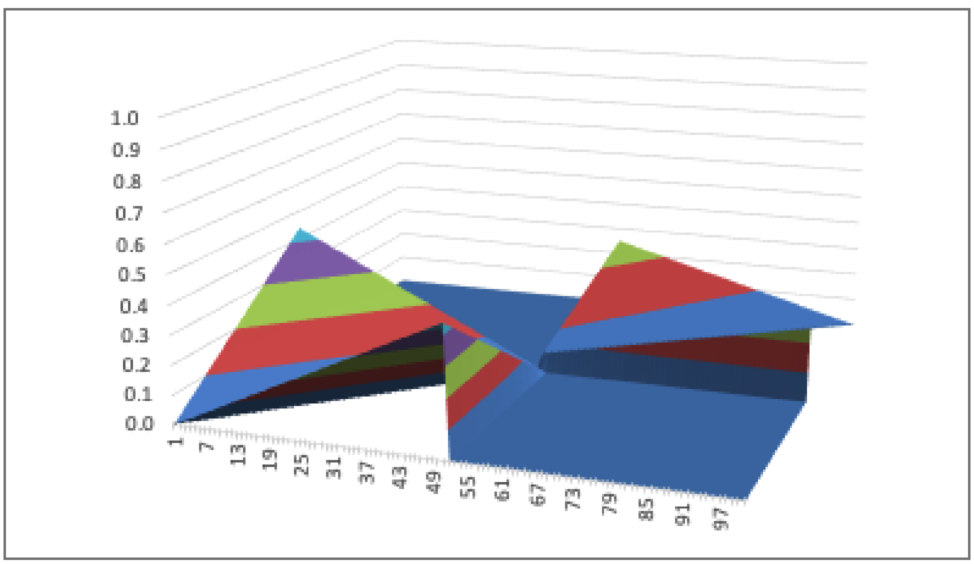


Figure 27. Regions of Group Utility Lost in Non-Cooperative Decision-Making for "Deadlock" and "Hawk-Dove".

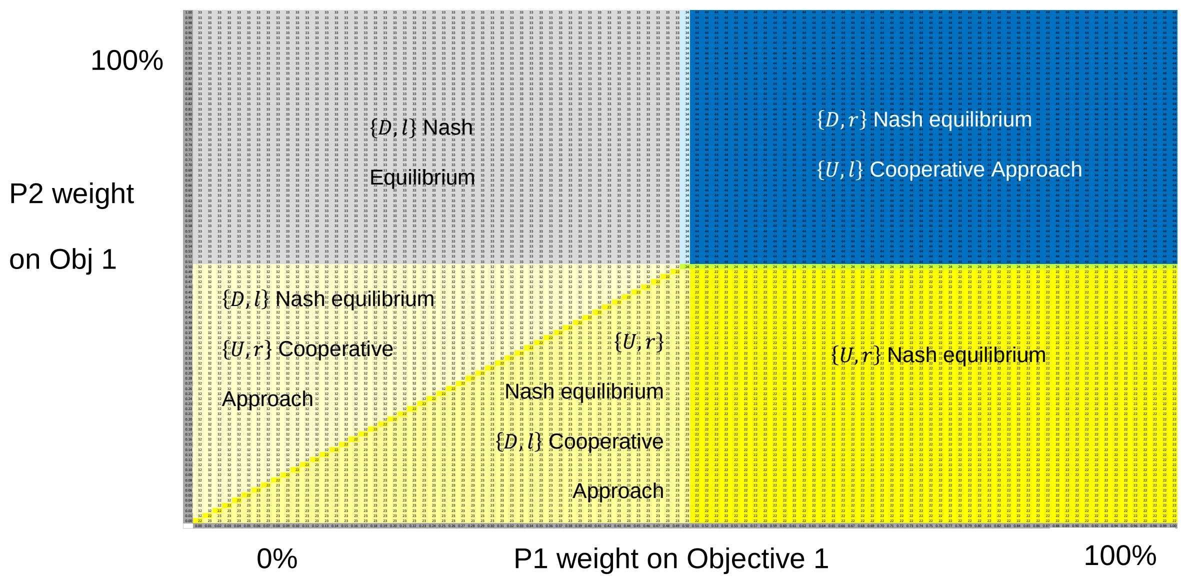


Figure 28. Regions of Pure Strategy Equilibria for "Deadlock" and "Hawk-Dove".

Table 2 shows a summary of these findings. Since we are using a linear additive function, the order of objective pairings does not produce a different result, so those repeated pairs are grayed out. Also, pairing the same game together as two objectives simply produces the same game structure, so those pairs are blacked out. The table indicates if the full space has a group utility loss or just partial. If partial, the table shows what the reason is for preventing a loss, either it is a mixed strategy region only, or there is only one equilibrium. To have a loss, there must be at least two equilibria in the final combined form.

3.5. Summary of Findings and Implications

1. All paired games show some combinations of objective weights for the decision-makers where there exists more than one pure strategy Nash equilibrium.

Table 2. Results of the Pairings of Games Indicating if the entire region (or part) has a difference between the Nash equilibrium and the optimal group utility.

	Matching Pennies	Harmony	Battle of the Sexes	Coordination	Anti-coordination	Prisoners Dilemma	Deadlock	Hawk-Dove	Stag hunt
Matching Pennies		Partial (1 Nash & Mixed)	Partial (Mixed)	Partial (Mixed)	Partial (Mixed)	Partial (Mixed)	Partial (1 Nash & Mixed)	Partial (Mixed)	Partial (1 Nash & Mixed)
Harmony			Full	Full	Partial (1 Nash & Mixed)	Full	Partial (1 Nash)	Partial (1 Nash & Mixed)	Full
Battle of the Sexes				Full	Partial (1 Nash & Mixed)	Full	Partial (1 Nash)	Partial (Mixed)	Full
Coordination					Partial (Mixed)	Full	Full	Partial (Mixed)	Full
Anti-coordination						Partial (1 Nash & Mixed)	Partial (1 Nash & Mixed)	Full	Partial (1 Nash & Mixed)
Prisoner's Dilemma							Full	Partial (1 Nash & Mixed)	Full
Deadlock								Partial (1 Nash & Mixed)	Partial (1 Nash)
Hawk-Dove									Partial (1 Nash & Mixed)
Stag Hunt									

2. Many pairings show a steep change in the group utility loss indicating that a small change in one of the decision-makers weights on an objective could generate a change in the "Cost of conflict" obtained and even the alternative chosen.

3. More non-zero payoffs in an objective create more instances of Nash equilibria and greater variety in change in the difference between the Nash equilibrium and the group optimal utility.
    a. "Stag Hunt", "Coordination", and "Anti-Coordination" show the most differences. All three of these have payoffs in all four of their quadrants
    b. "Matching Pennies", "Prisoner's Dilemma", and "Deadlock" have payoffs in all four quadrants but two of those quadrants have payoffs for only one decision-maker.
    c. "Hawk-Dove" has payoffs in three quadrants and shows interesting behavior in most pairings.
    d. "Harmony" and "Battle of the Sexes" have payoffs only in two quadrants on the diagonal.
4. Another factor was in the possibilities for combinations based on the variety of payoffs in the two objectives. The games modeling the objectives were scaled to have five payoffs (0, 0.25, 0.5, 0.75, 1). The more possible payoffs between the two objectives the more varied the behavior across the objective weighting space.
    a. "Matching Pennies" and "Harmony" have only 1 and 0 as payoffs. They had singular continuous planes as the difference between the Nash equilibrium and optimal group utility.
    b. "Battle of the Sexes" has three payoff values and all others had four payoff values. These combinations produced the most varied changes between the Nash equilibrium and optimal group utility.

The relative values of the payoffs clearly had impact, but the actual values themselves matter as well. For example, an objective modeled as a game with payoffs (0, 0.25, 0.5, 0.75) when combined with another objective has the same structure as an objective modeled as a game with payoffs (0.25, 0.5, 0.75, 1), but shifted in the weighting space. Additionally, other game types can be imagined which could reveal other behavior in the games not shown by the pairings in Table 2.

We can summarize the implications of this work in three key points:

1. **Non-Cooperative approaches are often sub-optimized for the group:** As Nash (1951) described, the Non-Cooperative approach does not necessarily find the optimal solution. In the combination of the various objective weights, the optimal for any individual can deviate from the group optimal.
2. **Objective weighting drives outcomes:** There are identifiable points where the outcomes change as the weights decision-makers place on each objective are varied. Even the simple two objective model shows some interesting behavior. As the weight that each player places on the two objectives changes, the number and location of Nash equilibria changes.
3. **Cooperation needs a signal:** To discover the group optimal solution, the decision-makers will need a signal to let them know what the possible full impacts are of their decisions. As the objectives increase and the number of decision-makers increase, their ability to discern the impact for any player will become more difficult and discerning the group optimal solution will become too difficult without some aided approach for the decision-makers.

3.6. Increasing Objectives

Exploring the impact of more objectives would provide a way to understand the changing nature of the final decision solution. We assume the same linear-additive utility function for each decision-maker as described at the beginning of this section:

$$u_m\left(c_{mj}^1(a_1, a_2), \dots, c_{mj}^{n_m}(a_1, a_2)\right) = \sum_{o=1}^{p} w_m^o \, u_m^o(c_{me}^o(a_1, a_2)) \text{ , where } \sum_{o=1}^{p} w_m^o = 1.$$

For these repeated trials, we increase n, the number of objectives, and examine $n = 3, 4, and\ 5$. The number of decision-makers remains as $M = |2|$ and the number of alternatives for each decision-maker, m, as $A = |2|$. Since we are beyond three-dimensional graphing, we use Monte Carlo Analysis to examine the “Cost of conflict” (the reduction in utility with non-cooperation) across 1,000 iterations in order to see the distribution. Figure 29 shows the distributions for the different number of objectives. In each repeated trial the objectives were randomly selected via a uniform distribution unique to each objective. The weight on the objectives by the two decision-makers was randomly selected via a uniform distribution unique to each decision-maker for each objective.

The tightening of the range of the “Cost of Conflict” is shows the mollifying effect that the increase in number of objectives has on the range of possible outcomes. The objectives are effectively cancelling out the impact of the other objectives as their number increases. Nevertheless, the range of the potential “Cost of Conflict” remains high with as much as 40% possible event with 5 objectives. The middle two quartiles still contain 10% “Cost of Conflict” with 5 objectives. Figure 29 shows that meaningful utility can be lost to the group across this entire range of objectives.

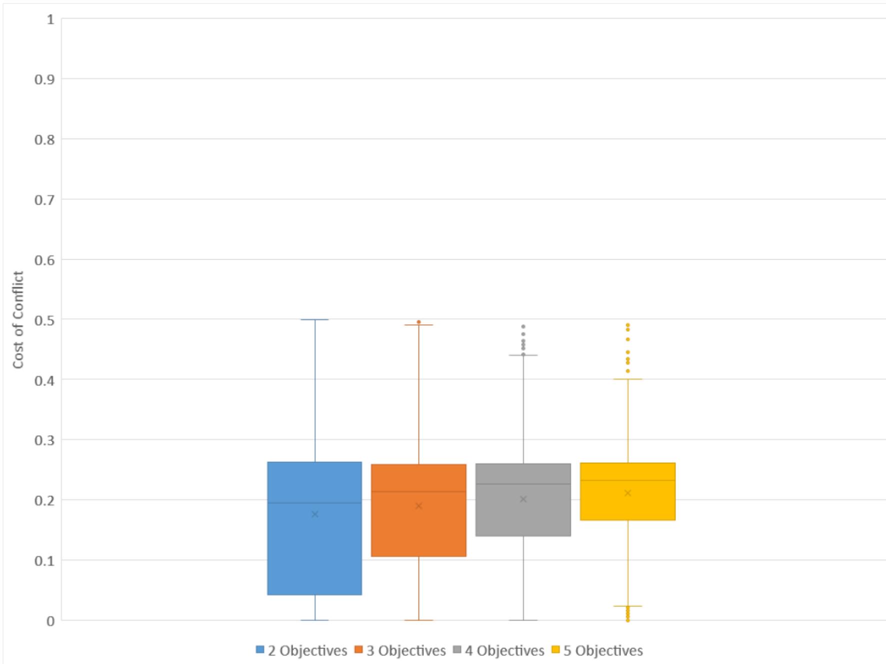


Figure 29. The Cost of Conflict with 2 to 5 objectives.

3.7. Contributions from the "Cost of Conflict"

Understanding that there are political behaviors in group decision-making is not new but re casting this game theoretic approach to be able to explore the behavior of supply chain coordination problems is insightful. As we showed in the above examples the construct of applying a Nash equilibrium as a solution concept for a game theoretic view of supplier-customer interactions can reveal where there is loss to the group utility because of the "Cost of Conflict". Using this approach as signal for two parties to see that there is a better solution will help them to move off of the Nash equilibrium on onto the Paretto solution.

Chapter 4. Social Network and Group Decisions

Game Theory provides an approach to understanding how the interaction of decision-makers impacts the group utility received from each objective. In a sense, this creates a process whereby the group can self-discover the interaction and impact of each decision-makers preferences on the overall group utility without the necessity of a decision analyst or some other facilitator to drive the process for them. The weighting of the decision-makers themselves (the $k_m's$ in Equation 2) remains as an element of the process to be improved. Additionally, we now make a clear distinction between decision-maker and stakeholder. Decision-makers are those whose preferences are directly included in the group decision. They are the actors in Equation 2. Stakeholders are the broader set of people that include decision-makers but also include those that influence decision-makers. Some stakeholders are not actors as in Equation 2; however, it is important to study them in a group decision because they influence what we will shortly define: Decision Power. Network Theory provides a tool to handle both issues: discovery of decision-maker weighting and impact of other stakeholders on the decision process.

The structure of knowledge transfer through a network was defined by Regan and McKelvey (2003) building on work in sharing best practices (Szulanski, 1996), new product development (Hansen, 1999) and even organizational survival (Baum and Ingram, 1998). Others have offered a knowledge-based theory of the firm where teams are social communities, where success is determined by efficient knowledge creation (by the individual) and dissemination (to the team). The effectiveness of this knowledge transfer is inferred to be from the strength of the ties between each person (Uzzi, 1996, 1997, 1999; Hansen, 1999). Hansen (1999) argued that the stronger the tie the better the ability to transmit complex knowledge. Regan and McKelvey (2003) go beyond the strength of a tie to consider how network structure, social cohesion, and network range affect the knowledge transfer process.

Of continued interest and study is the “closeness” of networks often described as degrees of separation. Interestingly, for many social networks, the average number connections (vertices) along a path can be very few compared to the length of a path. This result is referred to as the “small world” phenomenon which was famously coined and then studied by Travers and Milgram (1969), with further study by Pool and Kochen (1979), Watts and Strogatz (1998), as well as others. This has implications for understanding the true boundaries of networks in that the level of dense connections that are typically found make it difficult to discern a boundary to the network. An exogenously defined boundary as studied by Krackhardt & Stern (1988) and Lazega, (2001) are defined by some clear definition such as the confines of a city. An endogenously defined boundary initially defined by Freeman, Fararo, Bloomberg, and Sunshine (1963) is related to the group itself such as the data scientists within a business. Neither approach is definitive unless the boundary is truly crisp, therefore, choice of the boundary must be made carefully so as not to exclude a significant influencing stakeholder.

The study of networks themselves can be predictive of important characteristics of human behavior. Structural properties have been shown to be predictive of team performance and individual satisfaction at work as described by Bavelas & Barrett

(1951), but also on work power and influence in decision-making as studied by Brass (1984) and even success in bargaining and competitive settings as outlined by Burt (1992). All of these are relevant to the study of group decision-making in that they highlight how stakeholders are influencing each other as a significant determinant of the process groups use to make decisions.

4.1. Social Network Theory Background

Social networks across multiple decision-makers can be described as a graph. A graph is a structure that shows the relationship or lack of relationship between entities. It consists of two elements: vertices which are the entities, representing in this case stakeholders and decision-makers, and edges, which show the relationship between the vertices (stakeholders and decision-makers). More formally, a graph, G can be represented as $G = (V, E)$ where V is the set of vertices and E is the set of edges. The number of each of these elements can be represented using the cardinality operator. The number of vertices indicates the order of the graph, $n = |V|$ where n is the indicator of order. Set theory notation can be used to describe the groupings of elements of the graph. To understand the influence that one vertex may have over another, it is useful to know if the vertices are "connected." This would mean that there is a distinct set of vertices in series that (with their edges) create a path between two vertices. The existence of the path implies that the vertices could have influence over each other.

There are many ways to describe networks via graph theory at both the macro-level of the entire graph (stakeholder network) as well as the individual node-level (stakeholder). Many of these can be grouped into the broad category of centrality.

Bonacich (2012) places centrality measures into two broad categories: those that measure how important a node is in the flow through the network (often measured by shortest path) and those that measure the prominence of a node by its position (often measured as unique connections) in the graph. For the purpose of measuring the decision-power of a stakeholder, we will use the latter type of measure.

4.2. Social Networks and Influence in Strategic Group Decisions

In this research, we develop a theory of "decision power", the influence of stakeholders on a group decision, using social network theory.

The form of the decision-power weighting of a stakeholder will come in two parts. We consider the stated or extrinsic decision-power weight of stakeholder m, denoted w'_m, as compared to their intrinsic weight, denoted w_m, that they would use if making a decision without the influence of other stakeholders. Consider a group decision with p objectives, indexed $o = 1, \dots, p,$ to be made by n decision-makers, indexed $m = 1, \dots, n$. Decision maker m has the intrinsic weight k_{om} on the o-th objective, but her publicly announced (extrinsic) weight, denoted k'_{om}, is influenced by the other decision-makers. Let X be an $n \times n$ matrix representing connectedness in the social network of the decision-makers, so $x_{m,j} > 0$ if decision-maker, j, influences the weights of decision-maker, m, and the magnitude represents the strength of the influence. We assume that $x_{m,m} = 0$ for all m and $\sum_{m=1}^{n} x_{m,j} = 1$. Following DeGroot (1974), each decision-maker's extrinsic weight is a weighted sum of their intrinsic weight and the result of the influence of the extrinsic weights of the decision-makers who influence them. Let $\tau_m \in [0,1]$ represent decision-maker m's susceptibility to influence by other decision-makers and

$1 - \tau_m$ represent decision-maker m's reliance on her opinion. Decision-maker m's weight on the o-th objective is then given by

$$k'_{om} = (1 - \tau_m)k_{om} + \tau_m \sum_{\substack{j=1 \\ j \neq m}}^{n} x_{j,m} k'_{om}. \tag{9}$$

Let T denote a diagonal matrix of the τ_m then (9) can be re-written in matrix form

$$K' = (1 - T)K + TXK'. \tag{10}$$

This strength of connection can be determined in several ways. A few that are well described in the literature are:

1. Out Degree: The out degree is defined as the number of directed edges that leave a vertex. Using this approach assumes an equal weighting of vertices importance and then measures the number of connections that particular vertex has.
2. Swing Weights: Outlined by Keeney and Raifa (1976), this approach relies on the skill of a decision analyst to guide the stakeholders in making an assessment of their relative importance to a particular group decision.
3. Network Proxies: As described by Culota (2004) and Leskovec (2008), this approach uses a proxy measure such as number of emails or text messages going between decision-makers and stakeholders as an indirect, but empirical, measure of strength of connection.
4. Formal Position: This is the formal role that a Stakeholder has in an organization. It is often, but not always, expressed as a title such a Vice President. This is

readily determined through a formal organizational chart or human resources management system.

We think of the influence between stakeholders as a directed graph.

4.3. Deriving Extrinsic Weights

We can solve for the extrinsic weights using

$$K' = (I - TX)^{-1}(1 - T)K. \tag{11}$$

Thus, the term $(I - TX)^{-1}(1 - T)$ determines the combination of the individual's intrinsic weights and other stakeholder's intrinsic weights into each individual's extrinsic weights. This form does not simplify neatly because the inverse of $I - TX$ involves a polynomial of order n. To understand the implications, we will study its form for specific network structures with four decision makers.

4.3.1. Hub and Spoke

Suppose one decision maker has a central role in the network (see Figure 30), which implies that

$$X = \begin{pmatrix} 0 & x_{1,2} & x_{1,3} & x_{1,4} \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}.$$

Algebraic substitution of X for the Hub and Spoke configuration into (11) and simplification yields

$$k'_{o1} = \frac{(1-\tau_1)k_{o1} + \tau_1 \sum_{j \neq 1} (1-\tau_j) x_{1,j} k_{oj}}{1 - \sum_{j \neq 1} \tau_1 \tau_j x_{1,j}} \tag{12a}$$

and

$$k'_{om} = \frac{(1-\tau_m)\left(1-\tau_1 \sum_{m\neq 1 \& j\neq m} \tau_j x_{1,j}\right)k_{om} + \tau_m(1-\tau_1)k_{o1} + \tau_m\tau_1\left(\sum_{j\neq 1 \& j\neq m}(1-\tau_j)x_{1,j}k_{oj}\right)}{1-\sum_{j\neq 1}\tau_1\tau_j x_{1,j}} \quad (12b)$$

for $m \neq 1$. Each decision maker's extrinsic weight is a convex combination of their intrinsic weight and the other decision maker's weights. We examine next the relative influences of each on the extrinsic weight.

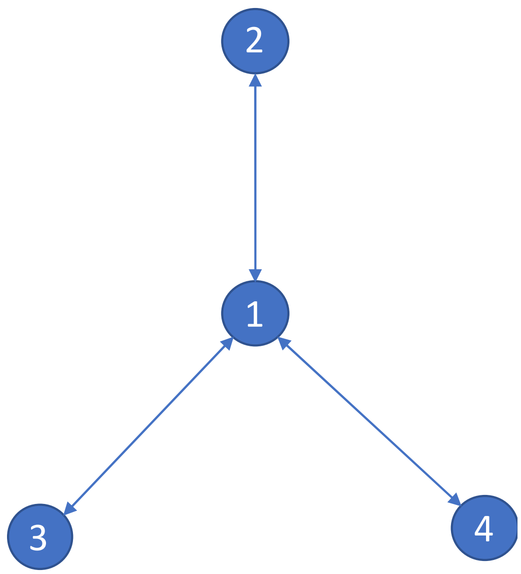


Figure 30. The network structure for the Hub and Spoke configuration.

The form of the hub decision maker's extrinsic weight in (12a) is simpler because she is connected to each spoke decision maker, but they are not connected to anyone else. The form for the spoke decision maker's extrinsic weight in (12b) is more complex as they are connected to the hub decision maker, but she is then connected to the other two spoke decision makers. The nested parentheses in (12a) and (12b) show the nature of the direct and indirect influence on the extrinsic weights.

In calculating the hub decision maker's extrinsic weight, her intrinsic weight is multiplied by a term proportional to $1-\tau_1$, while for spoke decision maker m's extrinsic weight, their intrinsic weight is multiplied by a term proportional to $(1-\tau_m)\left(1-\sum_{j\neq 1\&j\neq m}\tau_1\tau_j x_{1,j}\right)$. Thus, the hub decision maker will rely more on their own intrinsic weight if τ_1 is low, but for spoke decision-maker m to rely on his own intrinsic weight requires his τ_m to be low, and he has to resist second order influence of the other spoke decision-makers through the hub decision maker, represented by $\left(1-\tau_1\sum_{j\neq 1\&j\neq m}\tau_j x_{1,j}\right)$.

In calculating the hub decision maker's extrinsic weight, the spoke decision maker j's intrinsic weight ($j\neq 1$) is multiplied by a term proportional to $\tau_1(1-\tau_j)x_{1,j}$. Thus, the hub decision maker can be influenced by a spoke decision maker if τ_1 is high, the spoke decision maker's τ_j is low, and the network influence of the spoke decision maker on the hub decision maker ($x_{1,j}$) is high. In calculating spoke decision maker m's extrinsic weight, the hub decision maker's intrinsic weight is multiplied by a term proportional to $\tau_m(1-\tau_1)$ and spoke decision maker j's intrinsic weight ($j\neq 1$) is multiplied by a term proportional to $\tau_1\tau_m(1-\tau_j)x_{1,j}$. Thus, the hub decision maker can influence spoke decision maker m's extrinsic weight if their τ_1 is low and the spoke decision maker's τ_m is high. Another spoke decision maker can influence spoke decision maker m's extrinsic weight only through hub decision maker, requiring that the spoke decision maker's τ_m and the hub decision maker's τ_1 are high and the other spoke decision maker relies on their own opinion (low τ_j) and the network influence of the spoke decision maker on the hub decision maker ($x_{1,j}$) is high.

In most group settings, decision analysts simply average the stated (extrinsic) weights of each decision maker on a given objective ($\sum_{m=1}^{n} k'_{om}/n$). However, as we have seen, depending on the network influence structure of the group and the group member's reliance on their own opinion versus that of others, the relative influence of a given decision maker's intrinsic weight could be lower or higher than $1/n$. We can calculate the effect of k_{om} on the group weight. The relative importance of the hub decision maker's intrinsic weight in the group weight is proportional to

$$(1-\tau_1)\left(1+\sum_{j\neq 1}\tau_j\right),$$

while the relative importance of spoke decision maker m's intrinsic weight in the group weight is proportional to

$$(1-\tau_m)\left(1+\tau_1 x_{1,\mathrm{m}}+\sum_{j\neq 1\mathrm{orm}}\tau_1\tau_j\left(x_{1,\mathrm{m}}-x_{1,\mathrm{j}}\right)\right).$$

Each decision maker's intrinsic weight will be more important in the group weight if they rely on their own opinion (i.e. their own τ_m is low). However, they can also have more effect on the group weight through other decision makers. The hub decision maker has her own effect plus her effect on the spoke decision makers if they are susceptible, i.e. their τ_m is high. The spoke decision makers also have their own effect plus their influence on the hub decision maker, expressed by $\tau_1 x_{1,m}$, and their second order influence on the spoke decision makers, expressed by $\tau_1\tau_j\left(x_{1,m}-x_{1,j}\right)$. The second order influence of a spoke decision maker only adds to their relative importance if their effect on the hub decision maker ($\tau_1 x_{1,m}$) is greater than the other spoke decision maker's influence on the hub decision maker ($\tau_1 x_{1,j}$).

4.3.2. Chain

Suppose the decision makers are connected in a chain (see Figure 31), which implies that

Figure 31. The network structure for the Chain configuration.

$$X = \begin{pmatrix} 0 & 1 & 0 & 0 \\ x_{2,1} & 0 & x_{2,3} & 0 \\ 0 & x_{3,2} & 0 & x_{3,4} \\ 0 & 0 & 1 & 0 \end{pmatrix}.$$

No single decision maker serves the central role of the hub in the Hub and Spoke configuration, but the two outer decision makers are less connected and the two inner decision makers more connected.

Algebraic substitution of X for the Chain configuration into (11) and simplification yields k'_{o1} equal to

$$\frac{(1-\tau_1)(1-\tau_2\tau_3x_{2,3}x_{3,2}-\tau_3\tau_4x_{3,4})k_{o1}+\tau_1(1-\tau_2)(1-\tau_3\tau_4x_{3,4})k_{o2}+\tau_1\tau_2x_{2,3}(1-\tau_3)k_{o3}+\tau_1\tau_2x_{2,3}\tau_3x_{3,4}(1-\tau_4)k_{o4}}{1-\tau_1\tau_2x_{2,1}-\tau_3\tau_4x_{3,4}-\tau_2\tau_3x_{2,3}x_{3,2}+\tau_1\tau_2\tau_3\tau_4x_{2,1}x_{3,4}}$$

(13a)

and k'_{o2} equal to

$$\frac{(1-\tau_2)(1-\tau_3\tau_4x_{3,4})k_{o2}+\tau_2x_{2,1}(1-\tau_1)(1-\tau_3\tau_4x_{3,4})k_{o1}+\tau_2x_{2,3}(1-\tau_3)k_{o3}+\tau_2x_{2,3}\tau_3x_{3,4}(1-\tau_4)k_{o4}}{1-\tau_1\tau_2x_{2,1}-\tau_3\tau_4x_{3,4}-\tau_2\tau_3x_{2,3}x_{3,2}+\tau_1\tau_2\tau_3\tau_4x_{2,1}x_{3,4}}. \quad (13b)$$

The form of k'_{o4}, the other outer decision maker, is symmetric to k'_{o1}, and the form of k'_{o3}, the other inner decision maker, is symmetric to k'_{o2}. The order of the terms in (16a) and (5b) show the nature of the direct and indirect influence on the extrinsic weights.

In calculating k'_{o1} in (13a), decision maker 1's own intrinsic weight is multiplied by a term proportional to $(1-\tau_1)(1-\tau_2\tau_3x_{2,3}x_{3,2}-\tau_3\tau_4x_{3,4})$, which represents decision maker 1's reliance on their own opinion $(1-\tau_1)$ and her resistance to second-order influence by other decision makers $(1-\tau_2\tau_3x_{2,3}x_{3,2}-\tau_3\tau_4x_{3,4})$; decision maker 2's intrinsic weight is multiplied by a term proportional to $\tau_1(1-\tau_2)(1-\tau_3\tau_4x_{3,4})$, which represents decision maker 1's susceptibility to influence by other decision makers τ_1, decision maker 2's reliance on their own opinion $(1-\tau_2)$, and her resistance to second-order influence by other decision makers $(1-\tau_3\tau_4x_{3,4})$; decision maker 3's intrinsic weight is multiplied by a term proportional to $\tau_1\tau_2x_{2,3}(1-\tau_3)$, which represents decision maker 1 and 2's susceptibility to influence by other decision makers τ_1 and τ_2, the influence of decision maker 3 on decision maker 2 $x_{2,3}$, and decision maker 3's reliance on their own opinion $(1-\tau_3)$; decision maker 4's intrinsic weight is multiplied by a term proportional to $\tau_1\tau_2x_{2,3}\tau_3x_{3,4}(1-\tau_4)k_{o4}$, which represents decision maker 1, 2, and 3's susceptibility to influence by other decision makers τ_1, τ_2, and τ_3, the influence of decision maker 4 on decision maker 3 and decision maker 3 on decision maker 2 $x_{3,4}$ and $x_{2,3}$, and decision maker 4's reliance on her own opinion $(1-\tau_4)$.

In calculating k'_{o2} in (13b), decision maker 2's own intrinsic weight is multiplied by a term proportional to $(1-\tau_2)(1-\tau_3\tau_4x_{3,4})$, which represents decision maker 2's reliance on their own opinion $(1-\tau_2)$ and their resistance to second-order influence by other decision makers $(1-\tau_3\tau_4x_{3,4})$; decision maker 1's intrinsic weight is multiplied by a term proportional to $\tau_2x_{2,1}(1-\tau_1)(1-\tau_3\tau_4x_{3,4})$, which represents decision maker 2's susceptibility to influence by other decision makers τ_2, the influence of decision maker 1 on decision maker 2 $x_{2,1}$, decision maker 1's reliance on their own opinion $(1-\tau_1)$, and her resistance to second-order influence by other decision makers $(1-\tau_3\tau_4x_{3,4})$; decision maker 3's intrinsic weight is multiplied by a term proportional to $\tau_2x_{2,3}(1-\tau_3)$, which represents decision maker 2's susceptibility to influence by other decision makers τ_2, the influence of decision maker 3 on decision maker 2 $x_{2,3}$, decision maker 3's reliance on their own opinion $(1-\tau_3)$; decision maker 4's intrinsic weight is multiplied by a term proportional to $\tau_2x_{2,3}\tau_3x_{3,4}(1-\tau_4)$, which represents decision maker 2 and 3's susceptibility to influence by other decision makers τ_2 and τ_3, the influence of decision maker 4 on decision maker 3 and decision maker 3 on decision maker 2 $x_{3,4}$ and $x_{2,3}$, decision maker 4's reliance on her own opinion $(1-\tau_4)$.

4.4. Interpretation of the results of stakeholder network examination:

Reliance on own opinion $1-\tau_m$: As the decision-maker's reliance on her own judgement directionally increases her extrinsic weight will decrease. The greater her self-reliance, the less weight (extrinsic) she has as a member of the group. This is directionally true for all network configurations; however, the change is not linear. Especially for the lower values of τ_m, the vales of k will range greatly across the changes in k'. The reliance a decision-maker puts on her own opinion can have a dramatic effect on the weight she has in the group decision. At a low reliance on her own opinion, the decision-maker can have a very different extrinsic weight based on her intrinsic weight. With a high opinion of her opinion, decision-maker will have very little impact on her extrinsic weight no matter her intrinsic weight.

Impact of Intrinsic Weight (k): Generally, the higher a decision-makers intrinsic weight the higher her extrinsic weight will be. Additionally, a higher extrinsic weight will have impact on those decision-makers that adjacent to the decision-maker. This means the network configuration will have an impact on the relative extrinsic weights on the decision-makers. A well-connected, high-intrinsic weight decision-maker will lower the extrinsic weights of those decision-makers around her and increase her own extrinsic weight.

Implications: Location of decision-makers and broader stakeholders in a network as well as the network configuration itself can impact the relative weights of the decision-makers and ultimately the choice of alternatives. Decision-makers and stakeholders can alter the outcome by making connections in the network that allow a stronger intrinsic weight decision-maker to have greater influence on the decision by lowering the extrinsic weights of the adjacent decision-makers.

4.5. Characterizing the influence of stakeholders

We use the notion of Betweenness Centrality as described by Bonacich (2012) to examine the overall network in a more general form. Betweenness Centrality is based on geodesics (shortest paths) between nodes and is calculated through the following steps:

1. For each of the (n-1)(n-2)/2 pairs $\{j, k\}$ of nodes that do not include the subject node m, add all of the geodesics connecting j and k that include m.
2. For each of the (n-1)(n-2)/2 pairs $\{j, k\}$ of vertices that do include the subject vertex m, add all of the geodesics connecting j and k that do not include m.
3. Take the ratio of the two values and add up all of these ratios.

This sum is the closeness centrality of vertex m.

We make the calculations for the five-node network structure in Figure 32 and then tabulate them below in Table 3 or order to make a comparison between the nodes.

Table 3. Betweenness Centrality of Five Node Example.

Node 1

	2	3	4	5
2	X	1/2	0/1	0/1
3	X	X	0/1	0/1
4	X	X	X	0/1
5	X	X	X	X

= 0.5

Node 2

	1	3	4	5
1	X	0/1	1/2	1/2
3	X	X	0/1	0/1
4	X	X	X	0/1
5	X	X	X	X

= 1

Node 3

	1	2	4	5
1	X	0/1	1/2	1/2
2	X	X	0/1	0/1
4	X	X	X	0/1
5	X	X	X	X

= 1

Node 4

	1	2	3	5
1	X	0/1	0/1	2/2
2	X	X	1/2	1/1

Node 5

	1	2	3	4
1	X	0/1	0/1	0/2
2	X	X	0/2	0/1

3	X	X	X	1/1
5	X	X	X	X

= 3.5

3	X	X	X	0/1
4	X	X	X	X

= 0

This shows a calculated value for each vertex with vertex 4 being the highest. Given its location in the Stakeholder Network this follows intuition.

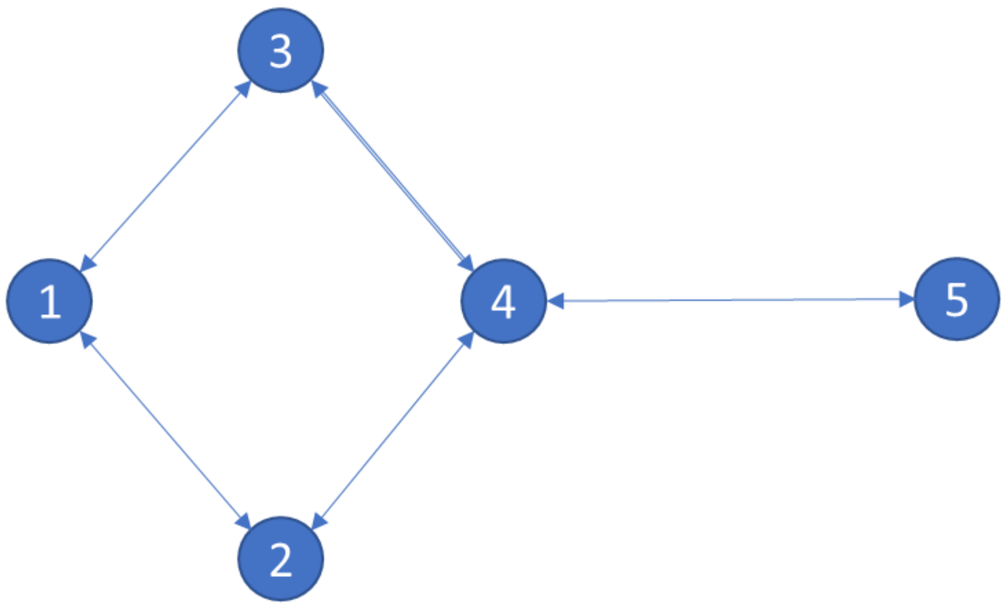


Figure 32. A five-node network structure.

We make a modification of the Betweenness Centrality to create the Strength Centrality. The same procedure is followed but the addition of each geodesic is replaced with the addition of each geodesic multiplied by its strength factor, $x_{m,j}$. To make the calculations more evident, we count every length of the geodesic not just the addition of the geodesic. This can be shown to be exactly equal to taking a proportion. The calculations are better seen in a series of tables one for each node. For this study, we set all of the connections at a strength of 1.0 except for the connections between node 3 and 4 $(x_{34} = 0.2)$. This is simply to show the impact that the strength of connection has on the weighting influence between stakeholders.

Table 4. Strength Centrality of the Five Node Example.

Node 1

	2	3	4	5
2	X	2/3.2	0/1	0/2
3	X	X	0/0.2	0/1.2
4	X	X	X	0/1
5	X	X	X	X

= 0.625

Node 2

	1	3	4	5
1	X	0/1	2/3.2	3/5.2
3	X	X	0/0.2	0/1.2
4	X	X	X	0/1
5	X	X	X	X

= 1.2

Node 3

	1	2	4	5
1	X	0/1	2/3.2	2.2/5.2
2	X	X	0/1	0/2
4	X	X	X	0/1
5	X	X	X	X

= 1.2

Node 4

	1	2	3	5
1	X	0/1	1/0	5.2/5.2
2	X	X	2/3.2	1/1
3	X	X	X	1.2/1.2
5	X	X	X	X

= 3.625

Node 5

	1	2	3	4
1	X	0/1	0/1	0/3.2
2	X	X	0/3.2	0/1
3	X	X	X	0/1
4	X	X	X	X

= 0

With only one connection in the network that is not at 100% strength, $(x_{34} = 0.2)$, there is still significant change in the Strength Centrality in all but the fifth node. This change is not seen in the Betweenness Centrality since it is counting only the existence of the connection not the strength of the connection.

We can apply this method to the two examples above, the Hub and Spoke (Figure 30) and the Chain (Figure 31) in order to determine their Strength Centrality.

Table 5. Strength Centrality for Hub and Spoke.

Node 1 (Hub)

	2	3	4
2	X	1/1	1/1
3	X	X	1/1
4	X	X	X

= 3

Nodes 2,3,4 (Spoke)

	1	3	4
1	X	0/1	0/1
3	X	X	0/1
4	X	X	X

= 0

Since all of the connections are through the center only Node 1 has any Strength Centrality no matter what the strength of the connections are between each of the nodes. This does not mean that the decision-maker at Node 1 (Hub) will carry more weight in the group. As the study above showed in addition to the number of connections and their strength, the decision-maker's weight will also be influenced by her reliance on her own opinion versus that of all other decision-makers. What this does, however, show is that for the decision-makers on the spokes of the network, the influence from all other decision-makers is moderated by the decision-maker at the hub. This is fairly evident from the network's simplicity but would be far less so with more decision-makers (nodes) and more connections with varied strengths.

Table 6 below shows the example of the Chain which has different Strength Centrality profile than the Hub and Spoke of Figure 30.

Table 6. Strength Centrality for Chain.

Node 1 (Left Outer)

	2	3	4
2	X	0/1	0/1
3	X	X	0/1
4	X	X	X

= 0

Node 2 (L. Inner)

	1	3	4
1	X	1/1	1/1
3	X	X	0/1
4	X	X	X

= 2

Node 3 (R. Inner)

	1	2	4
1	X	0/1	1/1
2	X	X	1/1
4	X	X	X

= 2

Node 4 (Right Outer)

	1	2	3
1	X	0/1	0/1
2	X	X	0/1
3	X	X	X

= 0

The Strength Centrality measure is now split between the two inner nodes (decision-makers). As we saw above the influence of the other stakeholders on the two outer nodes (decision-makers) is moderated through the two inner nodes immediately adjacent to each outer node. The Strength Centrality measure shows this easily since all of the strength of the network is concentrated in those two nodes.

4.6. Returning to the Motivating Example

We now return to the original example of the dissertation in Chapter 2. We described a group decision with six stakeholders Branch, Operations, Fraud, IT, Compliance, and Risk. The configuration of the network is shown in Figure 33 below.

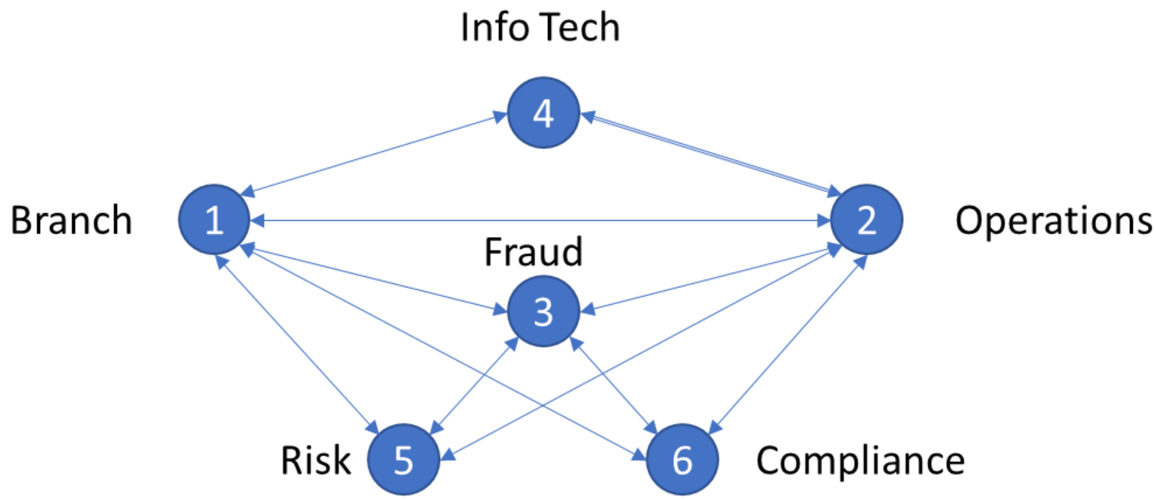


Figure 33. The network configuration of the six stakeholders from the bank example.

We elicited weights on five main objectives:

1. Minimize Cost Beyond Budget
2. Minimize Time to Completion
3. Minimize Associate Reputation
4. Maintain Brand
5. Minimize Delay in Realized Value

The elicitations were performed individually with each executive, allowing them to state their intrinsic weights. However, at the beginning of the program they did not want to share their weights because of a lack of trust in the group. We can now explore the question: What would the influence of the other stakeholders have been if the stakeholders had been forced to perform the elicitation in a group setting?

Based on knowledge of the executives involved, we estimated the connection matrix to be

$$X = \begin{pmatrix} 0 & 0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\ .15 & 0 & 0.3 & .15 & 0.1 & 0.3 \\ 0.8 & 0.2 & 0 & 0 & 0 & 0 \\ 0.4 & 0.4 & 0 & 0 & 0.05 & 0.15 \\ 0.5 & 0.4 & 0.1 & 0 & 0 & 0 \\ 0.45 & 0.45 & 0.1 & 0 & 0 & 0 \end{pmatrix}$$

As an example, we also estimated their susceptibility to influence based on the corporate culture

$$T = \begin{pmatrix} 0.7 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.6 \end{pmatrix}$$

The matrix $(I - TX)^{-1}(1 - T)$ in equation 11 used to derive the extrinsic weights from the intrinsic weights is (to two decimal places) is given below:

$$(I - TX)^{-1}(1 - T) = \begin{pmatrix} 0.38 & 0.15 & 0.15 & 0.18 & 0.08 & 0.06 \\ 0.08 & 0.57 & 0.11 & 0.09 & 0.06 & 0.08 \\ 0.16 & 0.12 & 0.57 & 0.08 & 0.04 & 0.03 \\ 0.08 & 0.13 & 0.05 & 0.65 & 0.04 & 0.05 \\ 0.07 & 0.10 & 0.04 & 0.06 & 0.72 & 0.02 \\ 0.13 & 0.20 & 0.08 & 0.11 & 0.04 & 0.44 \end{pmatrix}$$

Table 7 shows the weights elected from the executives on each top-level objective. Table 8 shows the extrinsic weights calculated from the intrinsic weights in Table 7 using the network model and our estimated X and T.

Table 7. The weights elicited from the corporate stakeholders.

	Minimize Delay in Realized Value	Minimize Cost Beyond Budget	Maintain Associate Reputations	Minimize Time to Completion	Maintain Brand
Branch	35%	25%	20%	15%	5%
Operations	35%	25%	20%	15%	5%
IT	35%	25%	20%	15%	5%
Fraud	60%	10%	10%	15%	5%
Compliance	35%	10%	5%	25%	25%
Risk	60%	10%	5%	5%	20%

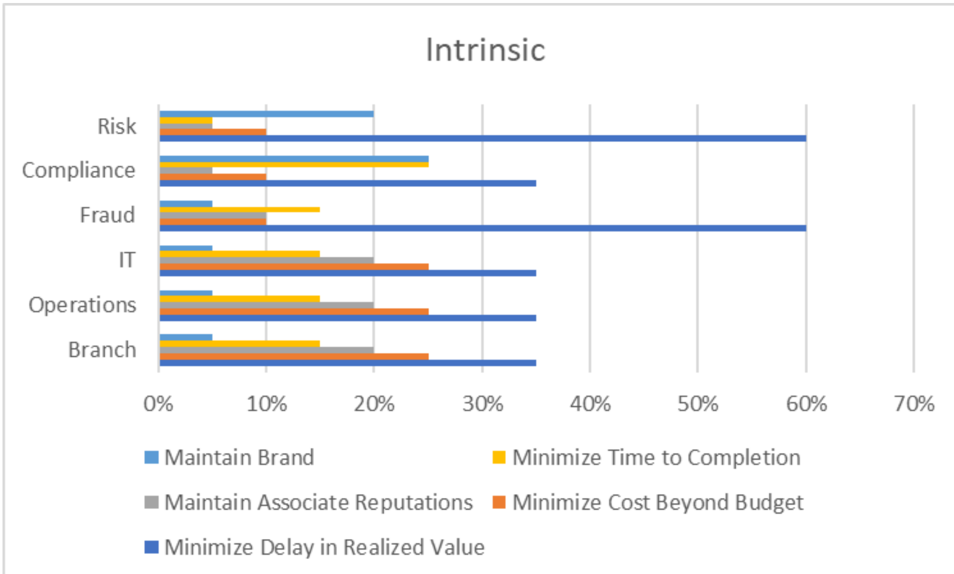
Table 8. The extrinsic weights for the corporate stakeholders from the network model.

	Minimize Delay in Realized Value	Minimize Cost Beyond Budget	Maintain Associate Reputations	Minimize Time to Completion	Maintain Brand
Branch	41.0%	20.3%	16.2%	15.2%	7.4%

Operations	39.4%	21.5%	17.0%	14.8%	7.3%
IT	37.8%	22.8%	18.2%	15.0%	6.2%
Fraud	52.5%	13.9%	12.2%	14.9%	6.5%
Compliance	36.9%	13.0%	8.3%	22.0%	19.7%
Risk	48.8%	16.1%	11.7%	11.0%	12.4%

Figure 34 shows the weights in Tables 7 and 8 as a line plot, revealing the real change in the weights when influenced by the social network. The extrinsic weights showed considerably less variance than the intrinsic weights, an effect that gives the impression of agreement as the stakeholders are not revealing their true preferences. This is significant and reveals one of the keys to the successful implementation of the decision described in Chapter 2. If the executives had been asked to state their weights in public, then they would have been subject to the social pressure inherent in the corporate culture to move toward a more consensus view without having actually had the conversation. They would anticipate what the weights should be. The level of trust which became critical to the success of the effort had not yet been built.

The difference in extrinsic weights from the intrinsic weights are significant and reveal the complexity in the interplay between the stakeholders as a result of the network configuration and the strength of their connections. As the ability of the executives to communicate improved inside of the program management structure to which they were comfortable, expressing ideas that were uncomfortable became more effective across the group. That trust would not have been built nearly as easily if the elicitation had been performed in a group setting. Individual elicitation was important for getting the fuller picture of how the executives thought about the objective weights. The ability of the fourth alternative to have arisen would have been dramatically diminished because the impact of the other alternatives on the objectives for some of the stakeholders would have been lost.



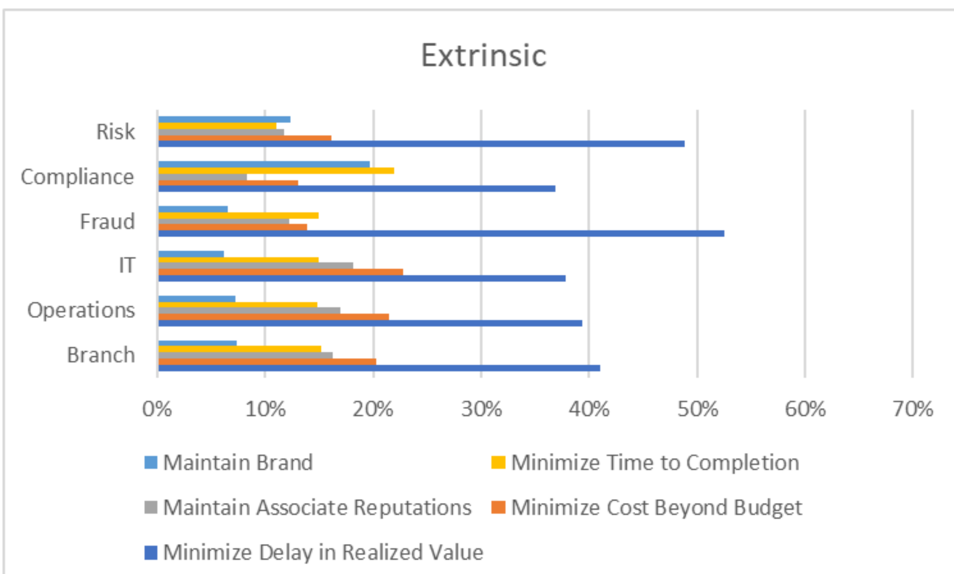


Figure 34. A Comparison of the Intrinsic and Extrinsic Weights of Each Stakeholder.

Returning to the Strength Centrality idea we can apply that to this five Node model of the stakeholders for our motivating example. We see those calculations in Table 9. Note the symmetry that we had before is gone, since strength of the connections between the bank stakeholders are no longer symmetrical. The tables read from row to column to indicate the strength of connections between two stakeholders. We see that the basic results we had achieved I the matrix analysis come through her as well. The Info Tech stakeholder because of relative isolation in the network has less influence than the other stakeholders. Risk and Compliance are also relatively low but not from their placement in the network but rather the relatively weaker connections that they have to the other stakeholders. Branch and Operations dominate because of both position and relative strength of connection. Unlike the ameliorating effective that we see as we calculated the extrinsic weights graphed in Figure 22, we again see the disparate strength that a subset of the stakeholders has and therefore the value of a private elicitation of weights.

4.7. Contributions from Stakeholder Network Analysis

This stakeholder network model provides an understanding of the decision-power of each stakeholder based on that stakeholder's connection to other stakeholders as compared to an assessment either collectively by the stakeholders or an outside decision analyst. The Strength Centrality measure provides a way to understand to what extent that decision-power is manifest in the weighting of the decision-makers. This model also implies that decision strength can change as the network changes.

Table 9. The Strength Centrality of the real example of the bank implementation.

Node 1	2	3	4	5	6	
2	0.00	0.92	0.99	0.75	0.39	3.04
3	0.83	0.00	0.76	0.75	0.64	2.98
4	0.29	0.51	0.00	0.49	0.42	1.71
5	0.44	0.52	0.55	0.00	0.39	1.89
6	0.41	0.50	0.52	0.44	0.00	1.86
Branch	1.97	2.44	2.82	2.43	1.83	11.50

Node 4	1	2	3	5	6	
1	0.00	0.29	0.29	0.27	0.36	1.21
2	0.17	0.00	0.24	0.30	0.21	0.92
3	0.00	0.00	0.00	0.00	0.00	0.00
5	0.32	0.31	0.52	0.00	0.16	1.31
6	0.32	0.31	0.52	0.12	0.00	1.27
Fraud	0.82	0.91	1.56	0.68	0.73	4.71

Node 2	1	3	4	5	6	
1	0.00	0.91	0.59	0.59	0.70	2.79
3	0.33	0.00	0.24	0.25	0.36	1.18
4	0.26	0.49	0.00	0.49	0.53	1.77
5	0.35	0.48	0.38	0.00	0.45	1.67
6	0.39	0.50	0.41	0.44	0.00	1.74
Ops	1.34	2.39	1.62	1.77	2.04	9.15

Node 5	1	2	3	4	6	
1	0.00	0.20	0.23	0.12	0.38	0.94
2	0.19	0.00	0.25	0.08	0.34	0.86
3	0.00	0.00	0.00	0.00	0.00	0.00
4	0.26	0.22	0.00	0.00	0.51	0.99
6	0.00	0.00	0.00	0.00	0.00	0.00
Risk	0.45	0.42	0.49	0.19	1.23	2.79

Node 3	1	2	4	5	6	
1	0.00	0.20	0.38	0.27	0.27	1.12
2	0.35	0.00	0.54	0.55	0.50	1.93
4	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00
IT	0.35	0.20	0.92	0.81	0.77	3.05

Node 6	1	2	3	4	5	
1	0.00	0.22	0.25	0.12	0.16	0.74
2	0.24	0.00	0.30	0.15	0.26	0.95
3	0.00	0.00	0.00	0.00	0.00	0.00
4	0.28	0.29	0.00	0.00	0.57	1.14
5	0.00	0.00	0.00	0.00	0.00	0.00
Comp	0.52	0.52	0.54	0.27	0.99	2.84

Stakeholders can change their influence on the decision by making better and stronger connections to other stakeholders thereby increasing their weighting in the group decision-making process. This change can alter the extrinsic weight of a stakeholder even though their intrinsic weight remains the same. This model also shows the impact that susceptibility to influence by others will have on extrinsic weight. As others are perceived to be more expert in a particular objective, the extrinsic weight of a stakeholder will change. Their extrinsic weight (true weight) is a function of three things: their position power, their strength of connections in the network, and their susceptibility to influence by others in the network.

Chapter 5. Conclusions

This work began (Chapter 2) as an application of a practical business decision: how "best" to rollout a complex, banking technology and process change to 10,000 employees across a 1000-branch network. It developed into a practical utilization of the latest thinking in group decision-making as encapsulated by Keeney (2013) but included important work from several others. We started with Freeman (1980), which originated Stakeholder Theory, and employed those ideas to increase the breadth of stakeholder groups that would be included in the multi-stakeholder decision. Freeman (1980) pointed toward the multi-objective, multi-stakeholder decision analysis construct as an appropriate use of Stakeholder Theory. We benefited from this insight by using it in a business group decision context. Values elicitation was done following Bond et al. (2008, 2010) but done in the context of typical business program meetings which were a comfortable format for the stakeholders engaged in the effort. From these elicitations, we developed multi-attribute utility functions for each stakeholder group. Because we suspected the presence of utility dependence, we followed Abbas (2011) and developed a utility function for stakeholders by creating utility trees. All of this culminated with employing the group decision-making approach in Keeney (2013). With this approach we developed a group utility function that increased buy-in from the stakeholders because of the transparency of the process. To help highlight the group impact of the possible alternatives, we relied on value-gap analysis methods (Merrick et al. 2005, Feng and Keller 2006) and used those methods to create a stakeholder value-gap analysis. The ultimate success of this analysis was to spur the group to create a new alternative that was an improvement over the original alternative set. A multi-objective, multi-stakeholder approach to decision-making took the stakeholders to a far more nuanced and robust decision-making process but resulted in a superior outcome than that achieved by three previous banks who had attempted to implement the same system and process changes.

Based on what was learned from the interactions of the stakeholders in the bank, we explored the formation of a model (Section 4) that would capture the "Cost of Conflict" for a group decision, if the decision-makers employed a noncooperative approach. The key component of this approach was to model the objectives using game theory. This required generalizing the one assumption that Keeney (2013) left as specific, decision-makers holding the alternatives in common. Instead, decision-makers could hold different alternatives. Those alternatives were used as the strategies in a game context where the normal form game was used to model the objective. The payoffs were the subjective utilities that each decision-maker held for that objective against their individually desired alternatives.

We examined nine different game forms and matched them in pairs through the possible combinations in order to understand where the "Cost of Conflict" would arise. Using the Nash equilibrium as our solution concept, we found that, in every pairing in some part of the weighting space, there was a "Cost of Conflict" meaning that the optimal solution would not be chosen consistently because the two decision-makers could land on a Nash equilibrium whose weighted payoff for the group was less than another possibility. We further explored the behavior of this modeling with game theory by examining the behavior with three, four, and five objectives modeled as games. By randomly selecting the games and the weighting placed by each decision-maker on each objective, we could look at the distribution of “Cost of Conflict” outcomes. We found that the range decreased as the number of objectives considered increased, implying that the increased number of objectives mitigated the “Cost of Conflict” from other objectives. All of these insights point toward further research into how the dynamics of group decision-making can be better modeled by employing other insights from game theory such as repeated games and information asymmetry. With this better modeling, practical applications can be developed that would aid in improving group decisions.

Returning to the core idea of Freeman (1980), we take up the examination of stakeholder interaction (Chapter 4) as a way to better determine the weighting of each decision-maker in the group decision. In the group decision for the bank system rollout, swing-weights, as described by Keeney and Raifa (1976), were used as a method to determine decision-maker weighting. By moving to network theory, we could create a measure of decision-maker weighting by understanding the “importance” of that decision-maker through the connections to other decision-makers. We further expand the frame by including the impact to a decision-makers importance by the other stakeholders who do not have decision rights but nevertheless have meaningful influence on the decision-makers. This is a further expansion of Keeney (2013) in that only decision-makers were considered in the formulation of the multi-objective multi-stakeholder model. We defined an extrinsic (true weight) of a stakeholder based on their intrinsic, which we suggest can come form their position power, and the connections they have to all other stakeholders. We defined a measure of the power of any one stakeholder by understanding their Strength Centrality, which gives an indication of the power of their position in the network. We solve for the extrinsic weight through our construct of Intrinsic weight, network connection, and susceptibility to influence.

The overall contributions from this work are first in the creation of a practical approach to implementing a group decision which, by following the construct of Keeney (2013), avoids Arrow's Paradox as described by Arrow (1951). This set of steps can be repeated for other complex group decisions which might otherwise literally experience "The Dictator" that Arrow (1951) describes. A consequence of Arrow's Paradox is that evaluations of alternatives do not reflect the values of the group, and potentially superior alternatives never surface as they did in the example from Chapter 2. The two conceptual components of this work, the use of game theory to model objectives and network theory to model decision-maker weighting, also point toward practical application for group decision-making.

Modeling objectives as games, requires the relaxation of the need for decision-makers to hold alternatives in common. As a result, the frame of the analysis is more fully open and allows the modeling of more complex decision problems. It also shows that there is an inherent possibility of group utility loss (Cost of Conflict) if the decision-makers have not committed to a fully cooperative approach. This commitment to full cooperation requires more interaction, than contemplated by Keeney (2013) and others, between the decision-makers to reveal the "Cost of Conflict" and chose the Paretto solution.

Modeling the interactions of stakeholders as a way to understand the weighting of decision-makers not only recognizes the difference between stakeholders and decision-makers, but also indicates a more quantifiable method of choosing decision-maker weighting.

Further research can explore the application of more aspects of both game theory and network analysis to group decision-making and thereby reveal ways to model other complexities of human decision interaction. This work has shown that there is value in using the techniques of those disciplines to understand better group decision-making and with those techniques implement better decisions.

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