INFORMATION CASCADES IN ENGINEERING DECISION-MAKING PROCESSES

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Abstract: Conventional wisdom is that early involvement of stakeholders leads to better results in engineering decision-making processes. A commonly documented advantage of early stakeholder involvement is increased acceptance and ownership of the project by everyone involved, resulting in fewer disputes throughout the planning and decision-making process. However, information cascade theory suggests that early involvement and development of close working relationships among stakeholders may decrease a group's ability to objectively and effectively evaluate engineering alternatives, as group members substitute the consensus of the group for their personal judgments. Additionally, innovation in design may be inversely correlated with the extent of group collaboration prior to selection of a preferred alternative. Experience in river engineering projects of the U.S. Bureau of Reclamation on the Rio Grande in New Mexico supports the idea that early stakeholder involvement, while effective in reducing disputes, has a suppressive effect on design innovation. Collaborative processes are intended to reach decisions with the benefit of the participants' diverse viewpoints and expertise. Interactions of the decision-making group should be structured to maximize disclosure of relevant information and encourage each participant to perform an independent, objective evaluation before consensus is reached, thereby ensuring that the intent of a collaborative process—that the group receives the full benefit of each member's knowledge—is achieved.

INTRODUCTION

A successful engineering project requires sound technical design. Additionally, cooperation and support from stakeholders are essential components of most projects. Accordingly, project planning processes often solicit stakeholder input early in the design stage to ensure that stakeholder interests are addressed in the final design and that stakeholders develop a sense of ownership and investment in the project. Early involvement and development of collaborative working relationships are widely advocated as means to increase stakeholder acceptance (Project Management Institute, 2004), as well as to reduce disputes, lower costs, and improve overall project quality (Miller et al., 2004). Stakeholders who have become integrated into the planning process are more willing to accept costs and operational changes, and stakeholder participation may be essential to the success of government-initiated projects that would fail if they were developed unilaterally by government agencies (Watson, 2004).

There is little dispute that collaborative planning with stakeholders is effective in minimizing disputes and increasing acceptance of projects. However, early and integrated involvement can reduce stakeholders' ability to independently evaluate prospective options for implementation. This tendency is consistent with information cascade theory, which suggests that people often make decisions by observing the choices of others, rather than by acting on their personal knowledge. Consequently, collaboration with stakeholders early in the project planning process may not be conducive to effective evaluation of the technical merits of project designs and, furthermore, can be suppressive to innovation.

INFORMATION CASCADE THEORY

The phenomenon of information cascades gained prominence in economics research in the 1990s (Banerjee, 1992; Bikhchandani et al., 1998). The theory states that, in certain situations where people can observe the decisions of others before making their own decision, the rational choice may be to disregard one's own private information and follow the decisions of others.

For a simple example (described by Bikhchandani et al., 1998), suppose that individuals decide in sequence whether to accept or reject a possible action. Accepting the action will either provide a benefit or incur a cost; the potential benefit and potential cost are of equal magnitude (e.g., accepting the action will either earn $100 or cost $100). Rejecting the action incurs no cost and provides no benefit. Each individual has privately known information about the likely outcome of the proposed action: a *positive* signal indicates that the action is likely to be beneficial, and a *negative* signal indicates that the action is unlikely to be beneficial. Participants can observe the previous decisions

of others but cannot observe the private information of others. All participants make mathematically rational decisions.

In this example, the first participant, Amanda, will decide solely on the basis of her private information, accepting if she has a positive signal and rejecting if she has a negative signal. If Amanda accepts, all other participants will correctly infer that her private signal was positive. If the second participant, Benjamin, also has a positive signal, he will have observed two positive signals: his own (known only to himself) and Amanda's (known to everyone). Consequently, Benjamin will accept the proposed action. However, if Benjamin's private signal is negative, then he will have observed one negative signal (his own) and one positive signal (Amanda's). In this case, Benjamin has equal information in favor of accepting and rejecting, so he is equally likely to choose each option (in theory, deciding at random). If the first participant has already accepted, Benjamin accepts 100 percent of the time his signal is positive and 50 percent of the time his signal is negative, so if he accepts, later observers will infer that it is more likely that Benjamin's signal was positive than negative.

After two individuals have made their choices, there are three possibilities: both participants accepted, both participants rejected, or one accepted and the other rejected. If the first two individuals accepted and the third participant, Caroline, has a positive signal, she will clearly accept. However, if Caroline has a negative signal, she will still accept because she has observed one clearly positive signal (Amanda's), one clearly negative signal (her own), and one signal that is more likely to be positive than negative (Benjamin's). Thus, her own negative signal is outweighed by the information obtained by observing her predecessors. Consequently, if the first two individuals both accept (or both reject), a cascade will be initiated, causing all subsequent participants to make the same decision, regardless of their private signals. As a further consequence, since Caroline and all subsequent participants accept based on the observed actions of Amanda and Benjamin, observers gain no additional information about the private signals of the third and later participants, so the 1000th individual has no more information about his or her predecessors' private signals than the third individual does.

If Amanda accepts and Benjamin rejects, or vice versa, Caroline infers that there has been one positive signal and one negative signal, which favors neither acceptance nor rejection. In this case, Caroline is in essentially the same situation as Amanda and will consequently accept if she has a positive signal and reject if she has a negative signal. The fourth participant, Darius, is then in a position analogous to that of the second participant, Benjamin. This sequence continues until, starting from a neutral position, two consecutive participants both accept or reject, at which point a cascade begins.

An additional implication of this example is that the order in which the private signals arrive can affect cascade formation. Signals arriving in the order *positive-positive-negative-negative* trigger a cascade in which everyone accepts, while the order *negative-negative-positive-positive* triggers a cascade in which everyone rejects.

In this example, cascade formation is likely to occur rapidly. Even if the signal is only correct 50 percent of the time (i.e., it has no predictive value whatsoever), a cascade will form after the first two participants 75 percent of the time. After eight participants, it is 99.6 percent likely that a cascade will have formed. As the accuracy of the signal increases, cascade formation is even more likely to occur.

Furthermore, the probability that an individual will make a correct choice by following a cascade is only slightly higher than when relying exclusively on the private signal. If P is the probability that the signal is correct, then the probability of a correct cascade forming when $P = 0.51$ (i.e., the signal is 51 percent likely to be correct) is only 51.3 percent, so observation of previous participants provides an increase in accuracy of only 0.3 percent (Bikhchandani et al., 1998). The benefit of observing previous participants increases slightly as the signal accuracy increases: a correct cascade will form 75.3 percent of the time when $P = 0.7$, and 85.7 percent of the time when $P = 0.8$. However, this increase in accuracy is relatively small, especially considering that the later participants may have observed thousands or even millions of others all making the same choice.

The preceding example is very simple: the only choice consists of accepting or rejecting a single option. However, information cascades can form in other, more complex, scenarios. Banerjee (1992) modeled a scenario in which individuals sequentially selected one of multiple options or could reject all options. In this model, some individuals received a signal, whereas others did not. To minimize formation of information cascades, the model assumed that whenever individuals were indifferent between following their private signal and following someone else's

selection, the private signal was always followed. Nevertheless, an information cascade could potentially form beginning with the third individual, and one would inevitably form at some point.

Theoretical modeling of information cascades usually assumes that private signals are received by individuals at no cost to themselves. In practice, obtaining a signal often entails non-negligible outlay of time, money, or both. For example, conducting research on a potential financial investment can be time-consuming, laborious, and even expensive. Similarly, obtaining information about almost any important decision, such as which car to buy or which university to attend, requires some expenditure of effort or other resources. As obtaining a private signal becomes increasingly costly, more people are likely to forego the expense and rely entirely on observations of others, which increases the tendency for information cascades to form.

In reality, some private signals are more accurate than others. People with expertise in a particular field generally have more accurate information about that subject than the average person does. For example, a professional photographer is likely to be highly knowledgeable about cameras. Individuals with high precision signals (i.e., experts) can affect how information cascades develop. A late-deciding expert can break a cascade by relying on his or her private signal rather than following the decisions of others. Alternatively, an early-deciding expert can singlehandedly initiate a cascade if others believe the expert's decision outweighs their own private signal (Bikhchandani et al., 1998). In practice, people may deliberately delay their decisions until the expert acts, causing a cascade to form very rapidly.

The implications of information cascade theory have obvious relevance to economics and financial markets. However, the theory also has application to such diverse subjects as crime, politics, medicine, fashion, and card games (Bikhchandani et al., 1998; Chapin, 2006). In general, information cascades are likely to occur in situations where participants sequentially choose from a discrete set of options and can observe the choices—but not the private signals—of their predecessors.

COLLABORATIVE DECISION-MAKING IN ENGINEERING

Consider the typical process for making decisions on an engineering project. First, the technical problem to be solved is stated and defined (e.g., a town's wastewater needs to be treated, or a school needs to be constructed to accommodate 2000 students). Second, multiple options for solving the problem are conceived and detailed. Finally, a decision maker (or decision-making group) selects one of the options for implementation. This process clearly fulfills one of the conditions necessary for the development of information cascades: choosing from a discrete set of options.

In contemporary practice, the decision-making body is usually composed of members with interdisciplinary expertise who represent a variety of viewpoints. This is particularly true for large-scale projects with multiple stakeholders, such as the construction of a new bridge, dam, school, or highway. There are often representatives from different agencies, companies, departments, communities, or whatever groups are relevant to the project. The intent is to ensure that the decision-making body considers varied issues related to the project, addresses the needs of all stakeholders, and uses its members' diverse expertise to evaluate which option is best. This approach may result in the decision-making body being composed of people who are initially distrustful of one another or whose interests conflict with one another. Such internal conflicts can create difficult working relationships and may cause delays or outright failure of the project. To address these potential problems, many authorities advocate that group members work together closely from the outset of a project to develop an atmosphere of mutual trust. This collaborative approach has been widely been reported to decrease conflict and improve stakeholder acceptance (Watson 2004; Project Management Institute, 2004; Miller et al., 2004).

Although improved group performance in selecting the best option is often cited as an additional benefit of increased collaboration, the evidence in favor of this conclusion is less compelling. Assuming that members of the decision-making group are competent and well-intentioned, they are likely to develop increasing mutual trust as they continue to work together. This will certainly decrease conflict, but it may also cause group members to accept each other's ideas with less scrutiny. If someone is trusted by other group members, his or her conclusions are more likely to be accepted without detailed examination of their underlying rationale, especially if he or she is regarded as an expert on a particular subject. In terms of information cascade theory, other group members observe an individual's choice but not his or her private signal. This, of course, is precisely one of the conditions necessary for the creation of

information cascades. If one or two trusted people recommend a particular option, the other group members may defer to their judgment, especially if performing an independent evaluation of the options (i.e., obtaining a private signal) requires a lot of effort. If this occurs, the supposed benefits of having a diverse decision-making group are reduced.

The inherent difficulty in collaborative decision-making is that the same mechanism—mutual trust—that reduces conflict and satisfies stakeholders simultaneously encourages group members to undertake less rigorous technical evaluation. Chapin (2006) summarizes the situation: "The interesting dilemma is that typically, the *more* influence a group's members exert on each other, and the *more* personal contact they have with each other, the *less* likely it is that the group's decisions will be wise." This conclusion runs contrary to the conventional wisdom that prolonged close collaboration produces better technical results.

Research on group decision-making suggests that group performance in problem solving is decreased when all members have close social relationships. Phillips et al. (2009) conducted a laboratory experiment in which groups of three people with pre-existing social ties were asked to solve a complex problem. After they had begun, they were joined by one additional person who in some cases had pre-existing social relationships with the others and in other cases did not. The heterogeneous groups (i.e., the ones in which the newcomer had no social ties to the others) were significantly more likely to reach the correct solution than the socially homogeneous groups. The higher performance of heterogeneous groups occurred regardless of whether the newcomer brought new or more accurate ideas; the mere presence of a socially distinct member caused the group to perform better, as time was spent more effectively to evaluate relevant information. In terms of information cascade theory, there was a greater tendency for individuals to disclose their private signals, not just their choices.

Another interesting result of this study was that the homogeneous groups, despite performing worse than the heterogeneous groups, rated themselves higher on a self-assessment of their performance (Phillips et al., 2009). In evaluating the group's performance, the participants were heavily influenced by their level of comfort with the group's social interactions. A similar inverse relationship between objective outcome and self-reported participant satisfaction was observed by Galinsky et al. (2002). These findings emphasize the inadequacy of using a group's self-assessment to definitively characterize the objective performance of the group; a close-knit, mutually-trusting group is likely to report high performance regardless of whether they have actually done good work. The conventional wisdom that close collaboration leads to improved technical results probably originates from self-reports of closely collaborating groups.

Synthesizing information cascade theory with experimental observations of group problem solving produces the somewhat unfortunate conclusion that stakeholder acceptance and satisfaction may be inversely correlated with the quality of a group's technical evaluation. Within the decision-making group for an engineering project, simultaneous achievement of both objectives depends on the ability of group members to develop mutual trust while still independently evaluating options and disclosing the rationale behind their choices. Once group members begin to defer to each other and an information cascade forms, the remaining members who follow the cascade are unlikely to express their views, even if they have useful or innovative ideas.

In some cases, such as when the technical aspects of the project are straightforward but stakeholders are contentious, it may be advisable to structure the decision-making group to maximize development of mutual trust, even if this leads to a less rigorous technical evaluation. Conversely, if stakeholders are cooperative and the project is complex, increased contention within the decision-making group may be tolerable in exchange for greater independence among group members and more careful technical evaluation.

CASE STUDIES: RIVER ENGINEERING ON THE RIO GRANDE

Between 2004 and 2009, the U.S. Bureau of Reclamation planned several river engineering projects on the Rio Grande in central New Mexico. The primary purpose of these projects was erosion control, with secondary focus on environmental restoration. The project locations are designated by river mile (table 1). All ten of the projects shown in table 1 are located within the land ownership boundaries of four different local communities (designated as Communities A, B, C, and D). Construction could not occur without the landowning community's full approval of project designs. Initially, each of the communities was somewhat skeptical that the projects were needed and would provide them with any benefit. Additionally, they were concerned about potential environmental damage to their

land, as well as the disruption caused by construction activities. Designs were developed first for the project at Community A, next for Community D, and later for Communities B and C nearly simultaneously. As of early 2010, construction is complete at Communities A and D but has not begun at Communities B and C.

Table 1. Characteristics of river engineering projects on the Rio Grande.

Project Location (River Mile)	Landowner	Stakeholder Involvement during Alternative Development	Difficulty in Selecting Preferred Alternative	Level of Innovation in Final Design
202.3	Community A	Low	Difficult	High
212.0	Community B	High	Easy	Low
213.4	Community B	High	Easy	Low
213.7	Community B	High	Easy	Low
215.5	Community B	High	Medium	Medium
223.9	Community C	Medium	Easy	Medium
224.6	Community C	Medium	Easy	Medium
225.1	Community C	Medium	Easy	Medium
228.9	Community D	Low	Difficult	High
231.3	Community D	Low	Easy	Low

For all projects, the alternative selection process consisted of developing several alternatives for each site and then choosing among them at a joint meeting attended by representatives of both the Bureau of Reclamation and the landowning community. In the design process for the projects at Community A and D, the alternatives for each site were developed with minimal input from community representatives and were then submitted to the communities for evaluation shortly in advance of the alternative selection meeting. For two of these three sites (River Miles 202.3 and 228.9) agreeing on a preferred alternative was difficult, as community representatives were dissatisfied with the alternatives as presented and demanded modifications. This was particularly true for the project at River Mile 228.9, where agreement on a preferred alternative required three separate meetings over a period of about two months.

Following this experience, the Bureau of Reclamation desired to reduce the difficulty in selecting a preferred alternative for the projects on Communities B and C. Accordingly, representatives from the communities were involved earlier and participated on the project team throughout the alternative development process. This approach was successful in reducing disagreement at the time of alternative selection. Of these seven projects, only one involved even moderate difficulty reaching agreement on a preferred alternative (River Mile 215.5); this was a site immediately adjacent to a historic residential area that was of very high cultural importance to Community B. The apparent benefit of early involvement by community representatives was that they developed comfortable working relationships with the Bureau of Reclamation and its design consultants, becoming confident of their expertise and good intentions by the time of the alternative selection meeting. The community representatives had less experience with river engineering projects, so they may have preferred to defer their decisions until they could observe the choices of others whom they perceived as knowledgeable. Representatives of Communities B and C offered relatively few comments and suggestions that affected alternative development, other than for River Mile 215.5.

Because these river engineering projects are either newly constructed or not constructed yet, objective evaluation of their long-term effectiveness is impossible. It is, however, possible to evaluate the degree of innovation in the final designs. For this purpose, innovation is defined as the extent to which the designs contained new ideas, as opposed to being a rehash of methodologies used on previous projects. The most innovative designs were for River Miles 202.3 and 228.9, which are the sites where coming to agreement on a preferred alternative was most difficult (table 1). In practice, innovation emerged from situations where the participants had reached a temporary impasse which could only be resolved by joint application of the insight and creativity of all stakeholders. If an impasse did not occur, the group was not motivated to innovate.

In the experience of the Bureau of Reclamation with river engineering projects on the Rio Grande, early stakeholder involvement reduced disagreement in selecting preferred design alternatives. However, the most innovative designs were developed for projects where there was low stakeholder involvement during alternative development and difficulty agreeing on a preferred alternative.

CONCLUSION & RECOMMENDATIONS

Early involvement of stakeholders in engineering decision-making processes leads to reduction of disputes and greater acceptance of project outcomes. In contrast to common belief, however, research indicates that close collaboration among decision-making group members usually correlates to less rigorous technical evaluation, which may decrease objective project outcomes and reduce innovation. As group members develop mutual trust, information cascades can occur, causing many group members to rely excessively on the judgment of a few others. Recent experience of the Bureau of Reclamation on river engineering projects on the Rio Grande in New Mexico anecdotally confirms these conclusions.

The goal of a collaborative decision-making process is to ensure that all participants' expertise, opinions, and preferences have appropriate bearing on the final decision. To support this goal, the structure and operations of the decision-making group should encourage participants to disclose all relevant information and engage in forthright discussion. Information cascades create an impediment to the free exchange of information among stakeholders and, thus, act in opposition to many objectives of collaboration.

Determining the best composition and structure for a decision-making group may depend on the relative importance of stakeholder satisfaction and thorough evaluation of alternatives. If getting the stakeholders to agree presents a greater challenge than the technical aspects of engineering for a particular project, then ensuring that group members cooperate closely and develop mutual trust will lead to a reduction of dispute and greater stakeholder satisfaction. In such a case, information cascades can work to create a benefit, as they increase agreement among people who would otherwise hold conflicting opinions.

In contrast, if some disagreement is tolerable in exchange for improved technical evaluation, it may be advisable to prevent group members from closely collaborating, at least until everyone has formed an independent opinion. Ensuring that everyone discloses his or her private signal, such as by requiring everyone to prepare an individual evaluation before the group meets to select alternatives, will prevent information cascades and ensure that the order in which participants disclose their choices does not unduly influence the opinions of others. Furthermore, legitimizing the social discomfort of disagreement can help people freely express dissenting opinions and realize that discussion of conflicting ideas improves, rather than detracts from, the group's performance. Innovation often originates from attempts to reconcile divergent viewpoints, and encouraging people to form and state independent opinions makes the group better informed, even if reaching agreement becomes more difficult.

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