Collaborative Problem Solving in Design Teams: Communication Patterns and Project Ambiguity

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Abstract:

This research examines how communication patterns within or between teams support problem solving in design and engineering projects. We compare four different perspectives for their effectiveness on performance: the *heavyweight project manager* perspective, the *internal communication* perspective, the *external communication* perspective and the *gatekeeper* perspective. We also propose that project ambiguity - i.e., the degree to which a project cannot be fully specified upfront - moderates how effective these different approaches are. Empirical analysis of data from 45 design and engineering teams shows that ambiguous projects require external communication, whereas non-ambiguous projects require internal communication with the project manager to be successful. Further, indirect communication through gatekeepers has little effect on project performance, but increases the performance evaluation of individual team members.

Keywords: Project Management; Problem Solving; Ambiguity; Communication;

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1. Introduction

Managing communication is a central aspect of modern project management. Projects require the coordination of interconnected tasks. They involve internal and external stakeholders which need to be 'kept in the loop'. They are vehicles of problem solving within organization, and often a catalyst of innovation, learning and novel ideas. It is not surprising that the project management institute's body of knowledge devotes a whole chapter to communication management. Project managers spend considerable time and effort managing the flow of information, and ensuring that the right people within their teams or beyond talk with each other.

Our research is focused on problem solving communication in design projects. It is well established that communication is an important factor driving project performance in that context. From the classical analysis of R&D projects by Thomas Allen (1984) to the comparison of Design-Structure Matrices with Communication Matrices in product development organizations (Sosa, Eppinger and Rowles 2004), academic research has emphasized the importance of project members communicating within or outside their team to enhance project outcomes. A basic thread underlying this research is an information processing perspective (Brown and Eisenhardt 1995, p. 358): "frequent and appropriately structured task communication (…) leads to more comprehensive and varied information flow to team members and thus, to higher performing development processes."

While the importance of communication for project performance is beyond doubt, the literature examining how communication patterns are related to project outcomes spans multiple disciplinary perspectives – project management, team communication and innovation. The literature is not only fragmented, but in some instances provides contradictory suggestions regarding the utility of different communication patterns. This is problematic since the literature has so far failed to provide an integrative perspective for project managers as how to structure problem solving communication in their projects. For instance, the product development literature emphasizes communication structures that are somewhat centralized by promoting the concept of the heavyweight project manager (Wheelwright and Clark 1992).

Research on team learning has emphasized the role of communication among team members (Edmondson 1999). Research on innovation management has highlighted the importance of communication with group-external people (Ancona and Caldwell 1992; Sutton and Hargadon 1996). Sociologist stress the role of structural holes in networks, and therefore the importance of indirect communication patterns through gatekeepers (Granovetter 1973; Tushman 1978). All of these perspectives correspond to very different forms of communication, and we need a broader view of the importance of these different perspectives, and a better understanding of the conditions where one perspective prevails over others. To this end, we address the following research questions: (1) How are the different problem-solving and communication patterns related to outcomes for individuals and for teams in design projects? And (2) what are the conditions under which some communication patterns are more effective than others?

The context for our research is problem solving in the execution of outsourced design & engineering projects in the petrochemical industry by an Engineering Design and Consulting firm located in India. Problem solving is an essential activity in design projects (Brown and Eisenhardt 1995). Design engineers have to combine their understanding of client specifications with their technological knowledge to generate an engineering deliverable appropriate to the project. While problems within these projects are often interlinked, they tend to be solved separately, which can result in problem solving iterations (Mihm, Loch and Huchzermeier 2003). For instance, an engineer needing to increase the rate of flow of liquids between two points in the course of designing the physical pipeline may choose to increase the diameter of the pipe carrying the liquid between the storage tank and reaction tank. However, this increases the surface area that of the pipe and can potentially lead to a temperature drop that may need to be accommodated by the process design engineer working on the desired chemical reaction. Such iterations highlight the need for communication within these projects, not only to coordinate the interlinked activities, but also to facilitate the search for innovative ideas for solutions, especially since the technology involved is often novel and unfamiliar to the team. . The outsourced aspects of these projects leads to communication in these project teams being predominantly driven by the internal coordination and problem solving needs of a particular project, and not by the need to coordinate interfaces with other

projects within the same organization. The teams working on projects in the design firm tend to be fluid, i.e. they are temporary organizational units that are dissolved after project completion (Huckman, Staats and Upton 2009).We proceed in the next section to theoretically discuss four different problem-solving communication patterns suggested by the prior literature. We then describe our data and measures in §3. Our data analysis and an interpretation of our results in provided in §4. We conclude our research, and discuss it's implications in §5.

2. Theory

From a managerial perspective, it is important to recognize features of communication patterns and recognize conditions when some forms of communication need to be emphasized more than others. Communication patterns in problem solving teams can broadly be conceptualized as being either direct or indirect. In direct communication, team members attempt to directly communicate with other team members, project leaders, or other colleagues within the organization. Alternatively, they attempt to indirectly communicate with a broader network of people whom they might not directly know how to access. Figure 1 provides an overview of the different communication patterns we analyze in our research. We essentially contrast four different perspectives: The heavyweight project manager perspective (Pattern I, also referred to as 'Leader'), which attributes importance to communication with the project leader; the internal perspective (Pattern II, also referred to as 'Internal'), which argues for the importance of team-members communicating with each other; the external perspective (Pattern III, also referred to as 'External'), which emphasizes the contribution of communicating with people outside of the team; and the gatekeeper perspective (Pattern IV, also referred to as 'Indirect'), which emphasizes the importance of indirect communications through gatekeepers. Note that for Pattern IV, we effectively aggregate communication through different gatekeepers, i.e. project managers, team members, or external colleagues, into a single pattern.

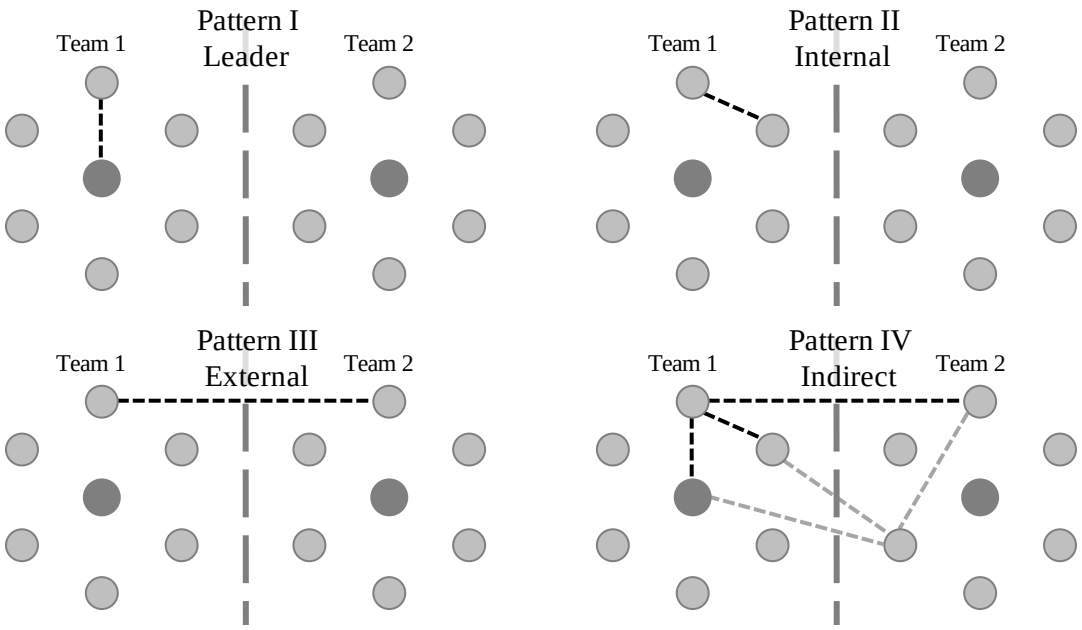

Figure 1: Communication Patterns in Project Teams

2.1 Direct Communication with Leader - Heavyweight Project Managers

A central contribution for the information processing perspective of development projects is the study of automotive development projects by Clark and Fujimoto (1991). An important insight in that study is to highlight the input of project leaders to problem solving in design teams. Project leaders have exemplary knowledge of customer requirements and of the other interlinked activities within the project. They are therefore in a unique position to coordinate the information flow between different project members. Clark and Fujimoto (1991, p. 260) differentiate lightweight leaders, who "spend a good deal of time each day reading memos, writing reports, and going to meetings" from heavyweight leaders, who "engage the bench level designer on the substance of the detailed design." This pattern of communication clearly leads to superior information being used to make decisions in projects and having such heavyweight project managers in the project has been shown to increase project performance (Gerwin and Barrowman 2002). This leads us to Hypothesize:

HYPOTHESIS 1A: *More problem solving communication between team members and project managers leads to increased project performance.*

2.2 Direct Communication among Members - Group Internal Communication

While project managers represent a formal communication channel for team members to utilize for problem solving, the question naturally arises to what degree other members of the project team are important alternative sources of ideas. There is a considerable amount of research that emphasizes the need for such within group communication for group learning (Siemsen, Roth, Balasubramanian and Anand 2009), and that explores the antecedents that makes within group communication more effective (Edmondson 1999). In general, empirical evidence supports the notion that group internal communication enables superior expertise coordination (Faraj and Sproull 2000) and increases group performance (Wong 2004; Bresman 2010).

Internal communication not only helps in sharing 'tricks of the trade' within the group, it also helps to build transactive memory systems, i.e. a shared understanding of who-does-what and who-know-what, which further facilitates the coordination of activities within the group. The benefits of internal communication are therefore often attributed to better coordination and efficiency within the group, rather than to more innovative problem solving (Wong 2004). Recent research however has suggested two effects that tend to make ideas obtained from other team members less innovative. First, ideas generated by team members tend to build on each other, draw on shared information and they are therefore similar (Kavadias and Sommer 2009). Successful problem solving, however, requires a high variance (and not a high mean) in the quality of ideas (Girotra, Terwiesch and Ulrich 2010). Second, teams exert (often subconscious) pressure for conformance, which further reduces the variance of ideas.

What then is the expected influence of group internal communications on project outcomes? Conventional wisdom holds that even projects with a clear emphasis on innovation tend to perform better with stronger internal communication (Katz and Tushman 1979). Other research suggests that increased emphasis on group internal communication is linked to reduced creativity (Teigland and Wasko 2003). Design is an activity that certainly has creative components, but also requires considerable coordination within the team (Brooks 2010). Do the coordination advantages inherent in internal communication

outweigh the potential disadvantages of reduced creativity? To test this question empirically, we hypothesize:

HYPOTHESIS 1B: *More problem solving communication among team members leads to increased project performance.*

2.3 Direct Communications outside the Team - Group External Communication

While the previous two hypotheses took a group internal perspective, there is considerable evidence for the importance of group-external communication for problem solving (Ancona and Caldwell 1992). Ancona and Caldwell highlight that teams not only need to manage the amount of external communication, they also need to manage the type of communication that takes place. Task oriented and problem solving communication has to be matched with political communication that has the purpose of securing resources and support for the team.

Prior work suggests that external communication can have a stronger innovative component than internal communication. Since team members tend to think alike, inputs obtained from observers external to the group can offer a more novel perspective (Wong 2004). External communication has thus been linked to increased individual creativity (Teigland and Wasko 2003). This logic implies that external communication may be more important for generating ideas and supporting innovative problem solving. However, external communication can also be problematic. Team members can communicate among themselves about their work related problems very effectively, since they have developed a shared understanding of the client and technology involved in their project. This shared understanding easily disappears across team boundaries, which can make inputs from sources external to the team ineffective and of limited use (Bechky 2003). Further, external ideas are often not appreciated since people can be defensive about their own work and suffer from the 'Not-Invented-Here' syndrome (Katz and Allen 1982). Nevertheless, several studies show the importance of such external communication for team performance (Zellmer-Bruhn 2003; Haas and Hansen 2005). Consistent with these findings, we hypothesize:

HYPOTHESIS 1C: *More problem solving communication between team members and group external sources leads to increased project performance.*

2.4 Indirect Communication mediated by Gatekeepers

The three previous hypotheses emphasized the importance of direct communication among different team members, between team members and project leaders, and between team members and external sources. It is, however, well established that a team often has gatekeepers, i.e. well connected individuals that manage communication with the outside and thereby span the boundary between teams (Tushman 1977). These gatekeepers, which can be project managers (Ancona and Caldwell 1992), but can also be other well connected team members (or other members of the organization), thereby have a monopoly over communication flows. They offer team members easy access to a broader network, but on the other hand, have the ability to steer information flows to their benefit.

The existence of gatekeepers naturally raises the question whether project managers should promote such indirect and mediated form of communication, or whether they should instead encourage employees to form direct ties and build up their own network. Empirically, high performing teams seem to include gatekeepers (Tushman 1977). In general, though, this question between direct and indirect communication links has been debated extensively within social network studies. On a broad level, this debate is one between network cohesion and brokerage (Fleming, Mingo and Chen 2007). Direct channels of communication create cohesive networks. Such networks, in turn, enable trust (Levin and Cross 2004), psycholgocial safety (Siemsen et al. 2009) and a common language with shared understanding (Uzzi 1997). Indirect channels of communication through gatekeepers create brokerage networks, which are larger and tap into a broader diversity of perspectives (Granovetter 1973). Gatekeepers are therefore in a unique position to channel communication that leads to innovative solutions to problems since they enable the assembling of knowledge from a larger number of sources with different perspectives (Burt 2004). Beyond that, the networks indirectly accessed through gatekeepers allow individuals access to a larger quantity of more diverse opinions. This not only increases the potential to find someone qualified

to provide an idea for problem solving, it also further increases the variance of possible ideas to implement in the solution to a particular problem.

Hansen (1999) summarizes this debate well by coining the 'search-transfer' problem. A broad network of weak ties has significant advantages in term of solution search, since it covers a broader quantity of ties and also is less likely to include redundant information and knowledge. A tight network of strong ties, however, has the advantage of knowledge and information flowing more easily through these ties, since the stronger relationships within these networks enable the transfer of tacit knowledge more easily. Empirically, both broad networks of weak ties and tight networks of strong ties have been associated with better performance, and so there is no clear argument either way (Fleming et al. 2007). For our research, this debate implies that we need to consider indirect communication as a separate possible communication channel. We therefore hypothesize

HYPOTHESIS 1D: *More problem solving communication that is mediated through gatekeepers leads to increased project performance.*

2.5 Project Ambiguity

Our objective in this study lies not only in a comparison of the effectiveness of these different communication patterns for problem solving, but also in identifying contextual variables that may explain when some forms of communication are more effective than others. To that purpose, we use the concept of project ambiguity, defined as the 'inability to recognize and articulate relevant variables and their functional relationships' (Sommer and Loch 2004).

Previous studies have identified the information processing requirements of a project (i.e. task uncertainty) as a key factor to determine the effectiveness of certain communication patters (Tushman 1978). However, as Schrader, Riggs and Smith (1993) point out, the concept of task uncertainty assumes that problem solvers have a good 'mental model' of the underlying problem, and problem solving therefore relies of getting good information on the parameters of this model. In other words, it emphasizes the coordinative function of communication, and less the innovative 'idea generating' function. In many problem solving environments, problem solvers do not have clarity a-priori about the underlying 'mental

model'. An essential process in problem solving is to reduce this ambiguity by developing a mental model. Developing such a mental model is not simply an exercise in information processing, but rather a creative process of innovation and trial and error learning. As such, project ambiguity is a different concept than project uncertainty, since it puts less emphasis on information processing, but rather stresses the creative aspect of adequately framing the problem and creating a mental model which can be filled with information later.

Recent research has therefore highlighted the role of managing project ambiguity for successful project management outcomes (Pich, Loch and DeMeyer 2002), and emphasizes that project management in projects with high ambiguity differs from project management in relatively clear (or less-ambiguous) projects. Ambiguity in design projects is often experienced as the absence of knowledge about essential functional variables that are important for the success of the project (Pich, Loch and De Meyer 2002). Traditional methods of planning and execution, which are essential for projects with low ambiguity, are replaced by trial-and-error learning in projects with high ambiguity (Sommer and Loch 2004).

While it is well known that higher task uncertainty requires more internal communication within project teams (Tushman 1978), the effects of project ambiguity on communication patterns is less understood. However, since there is empirical evidence that ambiguous projects really do require a different overall approach to project management (Sommer, Loch and Dong 2008) we would expect that ambiguous projects also require different communication patterns for problem solving than clear projects. In specific, we would predict that internal communication patterns are more important in unambiguous projects, since in such projects, problem solving is essentially reduced to information processing, and good project outcomes can be obtained by making sure that the right people have the right information within the project. However, ambiguous projects require extensive external communication patterns, since these communication patterns will lead to more diverse knowledge, which enables recombination of existing knowledge, and thereby innovation and mental model building. We hypothesize:

HYPOTHESIS 2A: *In ambiguous projects, external communication (either direct, or mediated through a gatekeeper) is more strongly related to project performance than in clear projects.*

HYPOTHESIS 2B: *In unambiguous projects, internal communication (either with project managers or other team members) is more strongly related to project performance than in ambiguous projects.*

3. Data and Measures

3.1 Data

Data were collected from 245 engineers in 45 project teams and their immediate supervisors from the instrumentation design division of a large global petrochemical engineering company located in India. The instrumentation group was a profit center in the firm and worked on instrumentation design projects for business units within the organization as for external clients. Project team members in the instrumentation design group were all collocated in one single storey office building. At the time of data collection, the division had 55 teams, we thus had a participation rate of 82%. Participation in the study was facilitated by an email broadcast to the group from the senior VP sponsoring the study requesting teams to take the time to fill out surveys. Participation in the survey was voluntary. All subjects spoke fluent English, the working language in the division. Most participants were male (83%), on average 30 years of age and many had at least a diploma (39%) or an undergraduate university degree (29%).

To obtain responses from as many members of each team as possible, we contacted each team willing to participate and scheduled a time for members to meet in a conference room to fill out our survey. Once each team had gathered in the room, they were briefed about the purpose of the study and provided instructions on completing the surveys. They were assured that responses would be kept confidential and that their individual responses would not be available to anyone in the company. We collected data using two different surveys: one for project team members and one for team supervisors. The Team member survey included measures of problem solving communication patterns and other interactions within the team.. For the teams that filled out our survey, we contacted the supervisors who filled out details of project characteristics, project performance and a set of individual performance items for each member of the team. Teams had 2 to 14 members, with the average group size being 5.4.

3.2 Measures

Each communication pattern from Figure 1 was measured for each individual team member. Note that Pattern IV was assessed using three different (sub)patterns, whereas Patterns I-III were single patterns. We provided a graph similar to Figure 1 to respondents while assessing the patterns. Table 1 summarizes the frames we used to describe these different patterns.

Table 1: Frames used for Problem-Solving Communication Patterns

Pattern	Frame
I (Direct-Leader)	You approach the leader of your team for help when you have a project related problem.
II (Direct-Internal)	You approach a member of your team for help when you have a project related problem.
III (Direct-External)	A member of another team provides help when you have a project related problem. You interact with that person directly.
IV (Indirect-Leader)	A member of another team provides help when you have a project related problem. You interact with that person indirectly through the team leader.
(Indirect-Internal)	A member of another team provides help when you have a project related problem. You interact with that person indirectly through a team member.
(Indirect-External)	A member of another team provides help when you have a project related problem. You interact with that person indirectly through your contact in another team.

For each pattern, we asked respondents for the frequency with which they use this pattern. Responses were made on a seven point Likert scale ranging from 1 (= Never Use) to 7 (= Use Very Frequently).We emphasize that these questions are framed as help seeking for a particular problem, and not as communication in general. Help seeking tends to occur simultaneously with information and feedback seeking, and leads to focused communication about a specific problem (Lee 1997).

In order to assess the impact of these problem-solving communication patterns on team performance, we need to aggregate these individual level assessments to the team. If these were individual level assessments of the team as whole, the standard procedure would be to assess intra-class correlations, and if team members sufficiently agree on their perception of team, we would average these individual assessments. However, our measures do not represent assessments of the team as a whole, but are firmly anchored at the individual level. Aggregation therefore needs to be discussed in more detail.

Three aggregation procedures seem feasible. We could (a) sum the individual scores in a team to create a team measure, (b) sum the standardized scores in a team to create a team measure, or (c) average the scores in a team to create a team measure. Method (a) would be appropriate if the team works on a single problem, but is influenced by the size of the team. The other two methods are not influenced by the size of team, and more appropriate if the team works on different (though interlinked) problems. Since the latter context more closely resembles our data context, we believe both (b) and (c) to be appropriate aggregation methods. We ran our analysis using both methods, and the results are consistent. We therefore use simple averages over individual scores when analyzing team performance.

Project ambiguity was assessed by project leaders on a three item scale. The scale was newly developed, since the only existing measure of project ambiguity was a single item retrospective scale (Sommer, Loch and Dong 2008)[1]. The following three items were used: "Initial specs were very ambiguous. Project involves technologies very familiar to us. This project involves few technical challenges for the team." Reverse coded items were re-coded before analysis. The coefficient alpha was .67 for this scale, which is adequate for newly developed scales. One should note, however, that since project ambiguity is used to test interaction effects, these interaction effects will be severely deflated by the measurement error remaining in the scale, and therefore much harder to detect (Busemeyer and Jones 1983).

Project performance was measured by the project supervisors' response to a single item measure: "Overall, I am satisfied with the current progress of the project." Since projects were ongoing, this overall measure of project performance seemed most applicable , since the objective measures of budgetary and schedule performance was not viewed as being uniformly meaningful across projects. Individual performance of team members was also assessed by supervisors rating each team member on their overall performance. Both of these measures were intended to be used as dependent variables, and random measurement error was therefore less of a concern.

[1] Sommer, Loch and Dong (2008) refer to project ambiguity as unforeseeable uncertainty.

Common rater effects should be of little concern in this study, since the dependent variables and most independent variables were assessed by different raters. The exception is project ambiguity, which is assessed by the same rater (the project supervisor) as the independent variable. however, project ambiguity is mostly used to analyze an interaction effect, and this interaction effect will be deflated (i.e. harder to detect) rather than inflated by method variance, and therefore cannot be an artifact of common rater effects (Siemsen, Roth and Oliveira 2010).

4. Analysis

4.1 Descriptive Statistics

The first step in our analysis is to better understand the distribution of different problem-solving communication patterns at the individual level. This serves two purposes. On the one hand, we need to establish that there is a meaningful degree of variation among these different communication patterns. On the other hand, we are assessing whether these communication patterns are really different aspects of communication, or whether they tend to be highly correlated. Table 2 provides an overview of our analysis.

Table 2: Descriptive Statistics of Communication Patterns at Individual Level

Pattern	Mean	Std. Dev.	Leader	Internal	External	Ind. (a)	Ind. (b)	Ind. (c)
I (Direct-Leader)	4.26	1.62	1.00					
II (Direct-Internal)	4.48	1.69	.34**	1.00				
III (Direct-External)	4.38	1.79	.35**	.34**	1.00			
IV (Indirect - Leader)	4.07	1.32	.14*	.15*	.13*	1.00		
Indirect-Internal	3.98	1.29	.11†	.16*	.09	.63**	1.00	
Indirect - External	4.00	1.31	.17*	.14*	.13*	.69**	.68**	1.00

Notes. ** $p \leq .01$; * $p \leq .05$; † $p \leq .10$

We make several observations. First, there is sufficient variation in all problem-solving communication patterns, i.e. all of them are observable to different degrees within the dataset. All patterns

tend to be used to the same extent within the organization since their means are similar in magnitude (with possibly the direct communication patterns being slightly more used than the indirect communication patterns). Further, the indirect communication patterns are highly correlated. In other words, when employees use gatekeepers to search for help, they tend to work through all the gatekeepers (project leaders, internal ones, or external ones) and not focus on one type. It is therefore appropriate to aggregate these three sub patterns into one scale.

While the direct communication patterns (Leader, Internal and External) are also significantly correlated ($r = 0.34$, 0.35 and 0.34, $p<0.01$), these correlations are not substantively large, since any factor shared less than 15% of its variance with the other two. There is some degree of overlap, i.e. team members that directly search for help with their problems do so via multiple channels, but also a clear indication of specialization, i.e. some team members prefer communicating directly with team leaders, others prefer talking to their internal team members, yet others resort to searching directly in their broader network of colleagues. Notice, however, that the correlations between direct and indirect communication patterns are positive and small. This is somewhat counter to the 'classic' gatekeeper perspective that sees these gatekeepers as central information flow monopolists within the team. Rather, our data suggests that while gatekeepers are used, team members do, in addition, draw on their direct network and communicate internally as they see fit. In other words, rather than being exclusive moderators of communication in teams, gatekeepers are one option that team members use, and are an option that does not substitute other forms of communication within the team.

As a first step to examine the usefulness of different communication patterns, we simply asked all team members to rate the degree to which they find these different communication patterns useful on a 7 point Likert scale. Interestingly, most patterns received exactly the same average rating (= 4.21) except for the external communication pattern, which received a 4.65. This indicates that at least on average, team members perceived the external communication pattern to be most useful for problem solving.

4.2 Project Performance

We now focus our analysis on explaining project performance. While we have many observations at the individual level (= 245), we have fewer observations at the project level (= 45). While this aggregation problem is common in team or project level research, it imposes severe limitations on what we can model using our data. In order to deal with the limitation on our sample, we refrain from using control variables in our estimation. This reduces the number of parameters estimated in our model. While this omission increases the risk of omitted variables bias, it reduces the risk of over-fitting our model. Further, to reduce the risk of a few influential cases driving the results from our analysis, we use robust regression to estimate our parameters (Rousseeuw and Leroy 1987). All variables were standardized. The model was estimated in Stata 11.1 using the 'rreg' procedure. The results from our robust regression analysis are summarized in Table 3 below.

Table 3: Robust Regression of Team Performance

	Model 1		Model 2	
	Est.	Std. Err.	Est.	Std. Err.
Project Ambiguity	-.34†	(.18)	-.15	(.15)
Leader	.00	(.21)	.24	(.17)
Internal	-.27	(.19)	-.28	(.19)
External	.18	(.22)	-.21	(.18)
Indirect	.00	(.16)	.11	(.13)
Leader × Ambiguity			-.67**	(.21)
Internal × Ambiguity			.04	(.19)
External × Ambiguity			.82**	(.19)
Indirect × Ambiguity			-.25	(.20)
Constant	.04	(.17)	-.03	(.14)
N	45		45	
F	.97		3.59**	

Notes. ** $p \leq .01$; † $p \leq .10$

The regression results in Table 3 provide interesting insights. First, note that for average levels of project ambiguity, none of the problem-solving communication patterns have a significant effect on project performance. There are, however, two significant interaction effects. The interaction between project-leader communication and project ambiguity is statistically significant ($\beta = -.67$, $p \leq .01$), and the

interaction term between external communication and project ambiguity is significant as well ($\beta = .82$, $p \leq .01$). Both of these interaction effects are in the direction predicted by Hypothesis 2. They suggest that communication with the project leader increases project performance only if project ambiguity is low, and communication with external team members enhances project performance only if project ambiguity is high. The opposite of these statements also holds true. Project performance decreases in high ambiguity projects if team members communicate more with their project leaders. The performance of a project deteriorates as well if team members resort to external help for problem solving in low ambiguity projects. We provide and overview of these effects in Figure 2, where we graph the predicted project performance, using the estimates from Table 3. We show the effects of communication with project leaders and external colleagues over the range of observed values for these independent variables. We also provide an overview how these effects change for different levels of project ambiguity, i.e. low ambiguity (1 σ below the mean), average ambiguity, and high ambiguity (1 σ above the mean).

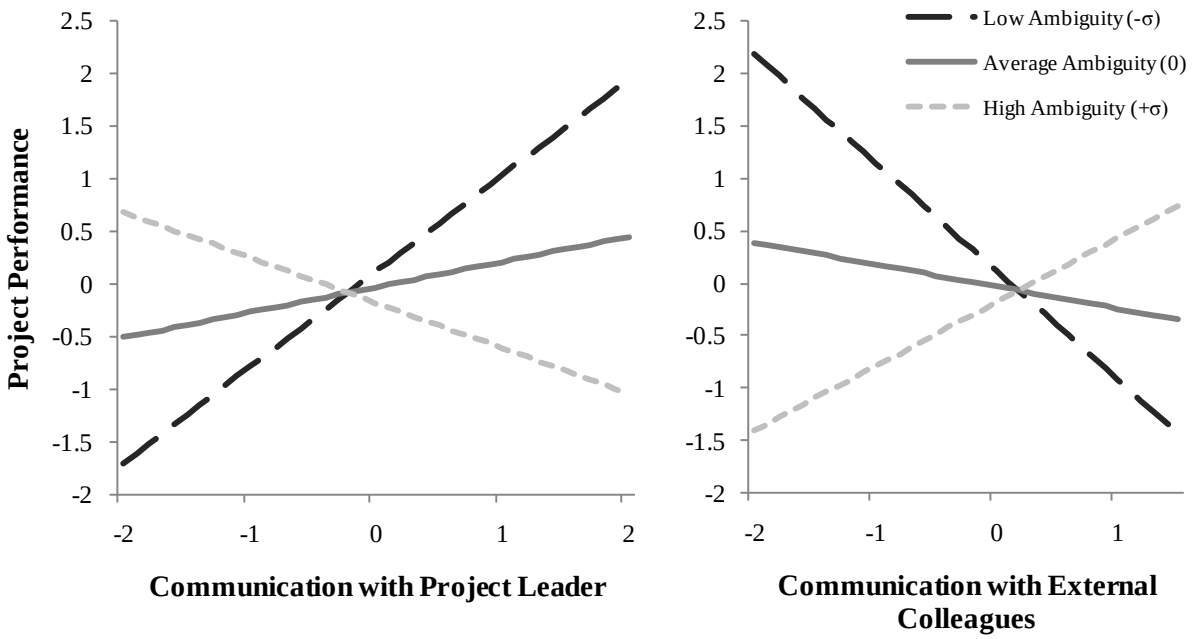

Figure 2: Communication Patterns and Project Performance

This analysis points to an important insight. Conditional on the type of project, i.e. ambiguous vs. non ambiguous, different communication patterns need to be emphasized for problem solving, and using the

'wrong' communication pattern for a given type of project can have very detrimental effects on project performance. The effect sizes are quite dramatic. As one can see in Figure 2, having the right form of communication present within a project shifts project performance from 2 standard deviations below the mean to two standard deviations above the mean, which is approximately the spectrum we observe in our data for project performance. Since this interval roughly corresponds to the range of observed values on project performance, these effect sizes indicate that having the 'right' communication patterns for problem-solving in place can make the difference between a project going really bad and really well. The right 'type' of communication pattern can make a project, and the wrong type of communication pattern can easily break it. Not only does having access to the 'right' knowledge improve problem solving, seeking the 'wrong' knowledge may be very detrimental to problem solving.

Surprisingly, we fail to find evidence that either internal communication patterns or indirect communication patterns are directly linked to project performance. A possible explanation may be that we do not have enough statistical power to detect these effects. Other explanations may be that the specific context of our study (outsourced fluid design projects in India) made these patterns less important. It is also possible that these patterns are more important in influencing individual performance than in influencing team performance. We will explicitly address this possibility in the next subsection.

In summary, we find limited support for our hypotheses of the direct effects of communication patterns on performance. Hypotheses 1a and c are supported in specific contexts, but there is no support for Hypotheses 1b and 1d. Further, Hypothesis 2a is supported for direct external patterns, but not for indirect patterns. Similarly, Hypothesis 2b is only supported for communications with project leaders, but not for communications with other team members.

4.3 Individual Performance

We now turn our attention to predicting the performance of individual project members. Analyzing individual performance has some advantages. A main advantage is the increased sample size, since instead of predicting the performance of 45 teams, we now predict the performance of 245 individual team members. A disadvantage, though, is that individual performance is less relevant than project

performance, since it does not capture the interlinked nature inherent in modern project management. Performance of teams does not necessarily depend on the average individual performance, but can be largely influenced by the 'weakest link' within the team. Indeed, the correlation between average individual performance and team performance in our dataset is $r = .13$ ($p = .41$), indicating the production function governing team performance in our context is more complex than the simple equally weighted linear sum of individual performance. Another disadvantage is that the subjective performance evaluations on team members made by project managers could be highly influenced by reputation, which is, in turn, also a function of communication patterns. This implies that any observed relationship between individual performance and individual communication patterns could simply be due to the reputation generated by these patterns, and not due to substantive and real contributions to the project made by the individual.

We conduct our analysis using regular OLS regression. In order to control for the hierarchical nature of our data, we use clustered and robust standard errors (with observations being clustered by project). Note that while project ambiguity in this analysis remains a team level variable, we now do not aggregate communication patterns across team members, but instead look at individual responses. Since we have more data at the individual level, we add control variables for subject age, gender and education. Results from this analysis are reported in Table 4.

Table 4: Regression of Individual Performance

	Model 1		Model 2		Model 3	
	Est.	SE	Est.	SE	Est.	SE
Project Ambiguity			-.01	(.05)	-.02	(.05)
Leader			.08	(.07)	.11†	(.07)
Internal			.01	(.06)	-.02	(.05)
External			-.02	(.08)	-.04	(.08)
Indirect			.41**	(.09)	.43**	(.08)
Leader × Ambiguity					-.03	(.07)
Internal × Ambiguity					-.03	(.05)
External × Ambiguity					.03	(.10)
Indirect × Ambiguity					.17*	(.09)
Age	.00	(.01)	.00	(.01)	.00	(.01)
Gender	.29†	(.16)	.22	(.17)	.21	(.15)
Education						
Diploma	-.32*	(.14)	-.25†	(.14)	-.22	(.14)
Bachelor	-.11	(.19)	-.11	(.17)	-.09	(.17)
Constant	.04	(.36)	-.08	(.34)	.02	(.32)
N	245		245		245	
R^2	.03		.22		.24	

Notes. ** $p \leq .01$; * $p \leq .05$; † $p \leq .10$

Interestingly, the problem-solving communication patterns that predicted team performance have less of an impact on individual performance. The effect of external communication is not significant (β = -.04, p = .63), and neither is the interaction effect of external communication with project ambiguity significant (β = .03, p = .79). Problem-solving communication with project leaders is only weakly significant (β = .11, p = .10). and the interaction effect of project leader communication with project ambiguity is not significant (β = -.03, p = .63). Neither is there any evidence that internal communication patterns have an effect. We do, however, see a strong effect of indirect communication patterns on individual performance evaluations (β = .43, p $\leq$ .01), and even the interaction effect between indirect communication patterns and project ambiguity is positive and significant (β = .17, p = .05).

This analysis points to an interesting asymmetry. In our context, project performance quite clearly depends on the right degree of communication between project members and team leaders, or project members and external colleagues, depending on the type of the project. These variables, however, have

little to do with individual performance. The team members which are seen by their team supervisor as high performers are those that utilize indirect communication patterns. A possible explanation may be that indirect communication patterns cast a broader net, and transmit an employees' name further throughout the organization, creating stronger reputation for that employee. This would suggest that it is good career advice to utilize indirect communication patterns. However, it is not necessarily sound project management advice to emphasize such communication patterns in project teams, since problem solving in projects depends much more on direct communication with either supervisors or external colleagues. We do, however, point out that using indirect communication patterns at least has no negative impact on project performance, and using direct communication patterns also has no negative impact on individual performance. These two objectives, individual career and project performance, are therefore not in direct conflict with each other.

5. Conclusion

This research has analyzed communication patterns in the context of outsourced design & engineering projects. There are two key findings in this research. First, we show that in ambiguous projects, problem solving communication should be focused on external colleagues, whereas in non-ambiguous projects, problem solving communication needs to be focused on project leaders. Second, we highlight that these communication patterns which drive team performance have little influence on individual performance. Rather, individuals within organizations are well advised to access indirect networks in order to benefit from the reputational gain of such networks.

Many of our hypotheses are not supported. We clearly show that some of the communication patterns which were predicted to have an effect made no difference in our context. This finding is surprising. The importance of project leader communication in non-ambiguous projects likely stems from the fact that in these projects, information processing is central, and the project leader is simply in the best position to manage information interfaces between the team, the client, and the broader organization. The

teams we analyze are fairly small, and therefore supervisors can fulfill this role effectively without facing an overly complex communication network.

We clearly show that simply relying on information flows and access to existing knowledge within the organization, i.e. standard procedures, design templates, etc., is actually detrimental in ambiguous projects. The innovation required to tackle these projects does not come from relying on existing templates and specifications that a supervisor has access to. Rather, ambiguous projects require external knowledge access, not only to create variance in ideas, but also to allow for re-combination of existing knowledge. However, if the project is not ambiguous, than accessing knowledge with high diversity and variation is detrimental for the project. Without ambiguity, project members are well advised to rely on existing templates and specification for problem solving that a supervisor can transmit to them, since such practices are usually well tested and derived from experience, and – if communicated through the supervisor – well aligned with client specifications.

These results echo the theoretical arguments by March (1991) about the differential value of exploration and exploitation in contexts of problem solving. Reaching out to the team leader provides several benefits to engineers encountering problems in the course of relatively unambiguous tasks execution. There are efficiencies from the reuse of learning from similar problems in the past that the leader is likely to be aware of. Approaching the leader is relatively easy on account of their physical proximity to the team and the interaction is also likely to be efficient on account of the leader's understanding of the specific context of the engineer's problem. These are characteristics associated with exploitation that is characterized by refinement and application of prior knowledge for task execution. In contrast, for ambiguous tasks, our results are consistent with March's suggestion that exploratory search by casting a wider net for inputs and seeking help external to the team is likely to be useful. Our results also underline the complex calculus of costs and benefits involved in patterns of help seeking. Clearly, exploration is more expensive in terms of effort and time spent following up on potentially useful but ultimately unproductive suggestions, and is justified only in the context of the solving of more ambiguous rather than less ambiguous problems.

Our empirical finding that indirect problem-solving communication patterns have little effect on team performance is certainly surprising, given the emphasis that has been placed on gatekeepers in new product development research (Tushman and Katz 1980), and the importance that sociologist usually ascribe to individuals who bridge the structural holes between networks (Uzzi and Spiro 2005). We emphasize that our data shows that these gatekeepers exist within our context, and they are used to varying degrees for problem solving communication. Their use, however, is not associated with better team performance. One possible explanation may be that these gatekeepers really act as information bottlenecks (Lovejoy and Sinha 2010), slowing down the speed with which team members can access different opinions within the organization. Direct external relationships allow much faster access to such opinions. The context of a 'fluid team' organization in our research is a conducive environment for people to develop these external relationships – after all, they work on a project for a year or two, and then move on to a completely different team with a different project. An organization that functions in this way really emphasizes the development of direct external connections, and as our data shows, these connections provide important benefits especially in ambiguous projects.

Empirically, much of the evidence that shows the importance of gatekeepers stems from before 1990. For example, Tushman's study of product development laboratories originated in the 70s (Tushman 1977), and the Uzzi and Spiro (2005) study of Broadway musical artists ends in 1989. In other words, this is data that cannot take into account the incredible efficiencies individuals gain in maintaining networks by using corporate intranets, email and social networking software. Maybe gatekeepers are simply less important in an age where direct connections are easy to maintain.

Our research questions the usefulness of 'Chinese Wall' policies in professional service contexts. Service providers like the one we study often have different teams working for competing companies. To prevent any knowledge spillover from one team to the other (and thereby to competing companies), these service providers usually employ a 'Chinese Wall' policy, i.e. they prohibit team members to communicate about their project within the organization. Arguably, ambiguous projects are most likely to result in 'Chinese Wall' requirements from a client, since they tend to involve more novel technology. As

our results indicate, such projects would benefit the most from team member communications about the project within the organization. This implies that clients face a dilemma when outsourcing ambiguous projects. They either insist on a Chinese Wall policy, and thereby risk that the contractor cannot adequately execute the project, or they loosen Chinese Wall requirements, thereby increasing the effectiveness of the contractor, but at the same time also increasing the chance of accidental knowledge spillovers to competitors.

Our results also suggest the need to recognize the broader logic of help-seeking in firms. For instance, it is in the context of ambiguous problems that contact with individuals outside the team, particularly experts is likely to be useful. Even if the external expert is unable to suggest a specific solution, he or she can provide inputs that are often more useful than an answer (Cross and Sproull 2004), such as the assurance that the approach the team is taking is likely to be fruitful or encouragement that motivates the team to persevere in their efforts.

Our research has several limitations. From a data perspective, our research is focused on a single company, and contains data of only 45 projects within the company. We make no claims that our findings are generalizable beyond the context of outsourced design projects. The low statistical power due to the small sample size may have lead to our failure on several occasions to reject the null-hypothesis. Further, since our research aggregates the analysis at the project level, and does not focus on particular problems within teams, we cannot fully show the mechanisms that underlie our observed effects. All interpretations of our results are therefore theoretical in nature.

As we show in our research, comparing the performance implications of multiple, different communication patterns is a fruitful exercise. Our research helped characterize how different patterns are important for different types of projects. As such, our research also serves as a framework to compare different communication patterns, and we hope that as such, it will stimulate further research in this area.

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