Reducing Work Related Uncertainty: The Role of Communication and Control in Software Development

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Abstract

This paper applies an organizational theories lens to the general problems incurred when organizations undertake unclear, poorly specified technical projects for which there are no easy solutions. In an empirical study of 57 software development teams, we investigate the impact of team member communication and team control strategies on role and task ambiguity experienced by team members. Results indicate that stakeholder rating of team performance is associated with decreased levels of role and task ambiguity. This finding goes beyond previous studies by showing the mediating impact of role and task ambiguity on the relationship between team performance on one hand, and team communication and control strategies on the other.

1. Introduction

This paper applies an organizational theories lens to the general problems incurred when organizations undertake unclear, poorly specified technical projects for which there are no easy solutions. The particular domain is software development which is demonstrably in trouble as seen by recent software systems failure at the Denver airport or the high cost cancellation of the Confirm travel reservation system [12]. This paper examines performance strategies during software development and describes how two perspectives on team performance, communication among team members and team control strategies, relate to increased software development team performance.

2. Communication and Control

For teams engaged in non-routine intellectual work in a complex projects, communication among team members is critical [5]. Effective communication can increase the likelihood of knowledge sharing. People can offer lessons from their previous experience and they can debate alternative perspectives. Communication also allows for knowledge creation as people use their previous experiences from similar problem domains to create new solutions to existing problems.

The effect of team communication and outcomes is an important research question that is not fully elucidated. For example, perhaps the act of knowledge sharing among people better enables task accomplishment because clarification, explanation and discussion makes it easier to perform the task. In this way communication reduces the task ambiguity; making clearer alternative approaches to the problem solution. The basic reasoning is that increased communication between knowledgeable team members makes the task more easily understood.

Task related communication may also enable mid-course correction. At the beginning of a work plan the task may appear clear, but as the work plan gets underway execution often drifts from the original plan. This occurs because individuals bring unique but often conflicting goals, opinions, and assumptions with them to the problem space. Communication about how others are approaching the problem, structuring their tasks and coordinating their efforts may enable the team to adjust their plans so that a more accurate view of the task exists, reducing the amount of task ambiguity experienced by individual team members [29].

This issue is significant in that people perform best those tasks that are clearly defined. Uncertainty and ambiguity in the minds of individuals can produce individual frustration and group conflict which in turn can lead to team disengagement as well as other productivity problems [25]. Without clear feedback, teams facing ambiguous tasks are often unable to assess progress and thus may find it difficult to meet their performance goals.

Effective communication also reduces the likelihood of team members experiencing individual role ambiguity. By comparing previous work expectations with current work load commitments in group discussions, communication helps to clarify expectations so that role ambiguity is less likely to occur. Furthermore, communication enables the sharing of pertinent methods for fulfilling a given role when team members face problems and demands that are unfamiliar to them.

Role clarity is also a critical requirement for performance gains in team-based projects. Similar to task ambiguity, role ambiguity (the opposite of clarity) may lead to loss of motivation, anxiety, and reduced productivity [19; 3]. Role structuring strategies enables team members to think more clearly about their individual contributions to and responsibilities for the team task [30; 11]. These processes are critical to achieving performance gains in a non-routine, intellectual, and highly interdependent work environment.

In an unconstrained problem space effective knowledge sharing and creation may never converge to feasible action. Hence, teams may also need effective control strategies in order to achieve performance goals. Effective control processes among team members are critical to ensuring that organizational members will internalize and act on organizational goals [10; 17]. Control strategies, often used synonymously with power and influence, demonstrate how actions by the manager as well as team members influence each other so that performance is achieved. For example, managerial control (the actions of the manager) ensures that team members behave in ways that meets the managers' needs and goals for the project. The manager may enact an outcome control strategy where he or she reviews the teams' outcomes on a regular basis or he/she may enact a process control strategy, providing input on day-to-day tasks and accomplishments. Likewise, team members may themselves enact control strategies. Team member or self-control refers to the teams' decisions to assign specific tasks, determine work methods and provide feedback [14; 23].

An important unsettled research question relates to whether control strategies have a direct effect on outcomes or whether their impact is contingent on interaction with other variables [21]. We argue that the act of influencing other members of the team to enact specific task strategies allows the development of a single, common view of the problem space and thus reduces task ambiguity. Often times through the manager's expert power (assuming the manager has had previous experience with a similar task and has been successful at completing that task) he or she is able to clarify and re-position the problem [33].

A crucial aspect of managerial control in complex technical environments is the ability of the manager to evaluate task progress. The choice of a control strategy depends greatly on the manager's ability to measure outputs or his/her knowledge of the transformation process [9; 27]. Thus, more than by the nature of his/her position, the manager's expertise in assessing task progress and measuring outcomes is an essential aspect of his/her exercise of control.

Team member self-control also influences the degree of task ambiguity experienced by individual team members. Specifically, if team members themselves decide upon the tasks and responsibilities for the team, they will presumably be better equipped to understand the task [24]. Taking responsibility for the management of the team requires more in-depth knowledge of the problem space so that well thought out plans can be made.

Control strategies specifically geared to make the task clear are important for a number of reasons. First, specific managerial-control processes lead to a central vision which enables uniformity of goals for team members [14]. Second, team-control strategies ensure that the team as a whole is more likely to buy-into a proposed solution and buy-in typically requires greater knowledge and understanding of the problem space.

Managerial-control strategies are able to supply critical missing information so that role expectations are clearly understood and team members' experienced role ambiguity reduced. A manager with well established control strategies (i.e., first perform this task and decompose the problem in this way) may be able to direct team activities and assign specific tasks [9; 15] which should help to alleviate role ambiguity. Furthermore, team self-control strategies may also enable role structuring. When team members get together to work on a highly interdependent task, there occurs a high degree of role ambiguity and, in turn, individual expectations and role assignments can not always be pre-defined. Responsibilities for task completion are undetermined as team members do not know exactly what is expected of them. Hence, self-control strategies could make a critical difference, enabling team members to clarify roles and share responsibility for the task and therefore reducing role ambiguity.

We argue that both communication and control strategies are crucial. Without control strategies that reduce ambiguities, teams may actually increase their degree of confusion. Our argument goes beyond previous research using communication and control theories by specifying a mediation process between these strategies and team performance. We test our argument within the context of a study of software development teams.

Given the previously stated rationale, we propose the following four hypothesis:

1) Task-related verbal communication reduces task ambiguity which in turn increases work team performance.

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2) Control (both managerial and self-control) reduces task ambiguity which in turn increases team performance.
3) Task-related verbal communication reduces role ambiguity which in turn increases work team performance.
4) Control (both managerial and self-control) reduces role ambiguity which in turn increases work team performance.

3. Methodology

3.1. Research design and sample

A total of 57 teams from 15 organizations participated in the study. The unit of analysis is the IS design team, since the intent of the study is to understand the behavior of organizational subunits (teams) rather than that of individuals or organizations. We chose software development teams that were working on relatively similar software design tasks. All of the project teams that participated in this study were surveyed at the end of the systems design phase of software development. We limited our research to mid-size development projects that were expected to last between twelve and fifteen months to complete. All of the projects had business application software as their design domain. Thus, these teams worked on a similar class of problems, were studied at the same development phase, and had relatively comparable size teams and project duration.

Fifteen organizations representing a range of industries participated in the study. For each software development project, two sets of questionnaires were distributed. The first questionnaire was distributed to the team members as they completed the design phase. The second questionnaire focusing on IS team performance was distributed to stakeholders familiar with the work of the team at the end of the project. These respondents were senior managers drawn from both the user (client) and the IS organization. We selected stakeholders that had intimate knowledge of the project's working and possessed a direct stake in its outcome. This approach is in line with the recommendation to use the most knowledgeable organizational informant [16].

A total of fifty-seven teams participated in the study. A total of 182 team members and 95 stakeholders are included in our analysis. The average age of team respondents is 35.4 years, 38.2 percent of the respondents are female. Job tenure at the current organization is 5.1 years, while professional tenure (years in this field) is 7.6 years. Team members have been reporting to their current supervisor for 1.2 years, and have been at their current position 1.8 years. 57.2% of the respondents have a college degree and 17.8% hold a masters degree or higher. The mean team size is 6.3 members. Table 1 summarizes our sample's characteristics.

Table 1. Description of study sample

Industry	Number of Companies	Number of Teams	Number of respondents
Insurance	4	11	44 (18)
Transport	2	14	42 (24)
High tech.	1	9	28 (17)
Financial Services	4	11	33 (17)
Petroleum	2	3	11 (5)
Heavy Industry	1	3	10 (6)
Education	1	6	14 (8)
Total:	15	57	182 (95)

Note: numbers in parenthesis in the respondents column represent the additional number of stakeholders that rated the teams.

3.2. Measures

Newly created and standard indicators were used to measure the constructs used in this study. Question order was randomized and selected items were reverse-scored in the actual measurement instrument to reduce response order effect. Each construct was derived by averaging the score of its underlying indicators. Individual responses were averaged in order to generate a team level score.

Managerial Expertise. This construct measures the expertise and control strategies of a manager in handling the technical tasks and managerial details of a project. We used four 7-point Likert scales drawn from [23] to measure the team's assessment of how well the manager understands the task, can accurately measure the work performed, is highly dedicated to the project, and has a high degree of technical competence. The scale scores were averaged across team members in order to arrive at a team score. The scores averaged 5.27 with a standard deviation of .63.

Team Communication. Each member of the team was asked to assess whether they had significant occasions to communicate and about the frequency of communication between team members. We used 2 Likert-like scales drawn from [23] to assess team communication. Team scores were computed from averaging individual responses. The score for all the teams averaged 5.97 with a standard deviation of .61.

Table 2 Summary Statistics and Correlations

Variables	# of items	Mean	S. D.	1	2	3	4	5	6
1. Team Self-Control	2	3.31	.75	1					
2. Team Communication	2	5.97	.61	-.27*	1				
3. Managerial Expertise	4	5.27	.63	.03	.22	1			
4. Task Ambiguity	3	4.18	.80	-.31*	-.19	-.13	1		
5. Role Ambiguity	4	3.74	1.12	.02	-.36**	-.35**	.43**	1	
6. Team Performance	4	5.17	1.07	.06	-.02	.21	-.39**	-.37**	1

N = 57; * p <.05; ** p <.01

Team Self-Control. Two items assess the team member's perception of the amount of self-control available to team members. Using two 7-point Likert-like scales members rated their ability to control how they do their work and what they will work on. Team scores were computed from the average of individual responses (mean = 3.31, s.d.=.75). These measures of self-control were drawn from [23].

Role ambiguity. Role ambiguity corresponds to the conceptual reverse of role clarity. We used four Likert-like scales based on [30] to assess role ambiguity. The scores averaged 3.74 with a standard deviation of 1.12.

Task ambiguity. Task ambiguity refers to the information processing load experienced by a team as it engages in its task activities. We used 3 Likert-like scales drawn from [6] as a measure of work-unit information equivocality. The scores averaged 4.18 with a standard deviation of .80.

Team performance Measures. We used stakeholder to assess team performance. Stakeholders are individuals who are not team members but who can affect design activities and who can be affected by the resulting IS. These stakeholders assess performance based on their knowledge of the organizational needs, experience, and quality expectations. Four Likert-like scales, based on [14; 13] were used to measure group performance as assessed by project stakeholders at the end of the project. The scores averaged 5.17 with a standard deviation of 1.07. Table 2 provides the summary statistics and correlations between the constructs.

3.3. Measurement properties

The indicators were analyzed for measurement properties, reliability and validity. For the vast majority of the teams we obtained responses from all team members. This high rate of team coverage provides confidence in the overall representativeness of the responses for the behavior of the team as a whole.

Level of analysis. The values assigned for each indicator at the team level is the mean value of all responses to that question by members of the team. In order to justify aggregation of survey data from the individual level to the group level, a oneway analysis of variance was undertaken for each of the constructs. Results indicate that the within-group differences were significantly less than the between-group differences for all of the six constructs (managerial skill was marginal with a *p*-value of .055).

Internal Consistency of Measurements. We used a confirmatory factor analysis approach to measure the internal consistency of the measures underlying each construct. The analysis was undertaken at the individual response level and was operationalized using the LISREL framework [18]. The composite reliability index (analogous to Cronbach's alpha) evaluates the internal consistency of the indicators underlying a construct by calculating the proportion of trait variance accounted for by the measures (see [2]).

Table 3 provides the composite reliabilities for each of the six constructs included in this study. We ran each set of related constructs (control and communication, role and task ambiguity, and team performance) separately. The values of the composite reliabilities are: managerial expertise = .81, team communication = .83, team self-control = .68, task ambiguity = .82, role ambiguity = .81, and team performance = .76. All of our constructs noticeably exceed the recommended minimum level of .6 (that at least 60 percent of the variance is due to the trait) [2].

Convergent and Discriminant Validity. Convergent validity in a confirmatory factor analysis framework is the amount of agreement among measures of the same trait. An examination of table 3 indicates that the t-values underlying each indicator in the model are statistically significant, thus indicating acceptable convergent validity. Additionally, the result of testing the measurement model indicates an acceptable fit to the model--team characteristics: Chi-squared (*df*:17) = 23.79, $p < .130$; process characteristics: Chi-squared (*df*:19) = 24.80, $p < .025$; and project outcome: Chi-squared (*df*:2) = 3.75, $p < .150$.

To investigate discriminant validity, we tested to see if the correlation between pairs of dimensions are significantly different than one. This analysis requires the comparison between a constrained model whose inter-construct correlations are set to one and the unconstrained model. If the constrained model exhibits a significantly higher Chi-squared value compared to the unconstrained model, then discriminant validity has been supported. Tests of the constrained model yielded the following results: for team characteristics: Chi-squared (*df*:20) = 185.56, $p < .000$, and for process characteristics: Chi-squared (*df*:14 = 190.98, $p < .002$. Both differences in Chi-squared are significant: for team characteristics the difference (*df*: 3) was 161.77, *p*=.000, and for process characteristics the difference (*df*: 1) was 166.18, *p*=.000, thus providing support for the discriminant validity of our measures.

3.4. Model Specification

Traditional model evaluation generally tests hypothesis within the standard regression framework with the measurement properties of constructs being assessed using factor analysis and simple internal reliability indices such as Cronbach's alpha. The alternative approach is to specify a set of structural equation models as a comprehensive means for assessing and modifying theoretical models. Under such an framework, the measurement model and the structural relationships are evaluated simultaneously using covariance structure modeling packages such as LISREL (for details on the analytical methods, see [18]).

Generally, researchers chose either traditional statistical analysis or structural equation modeling in order to model their results. Because we are studying a team-level phenomena using aggregated individual-level responses, we were faced with the need to investigate the measurement model at the individual response level (n = 182) while the structural model relied on a smaller number of teams (n = 57). We chose to test our measurement model using LISREL

Table 3: Parameter Estimates for the Theoretical Model

Construct (Composite reliability)	Lambda (*t*-value)	Lambda (standardized)
Team characteristics: Chi^2 (*df*:17) 23.79; $p < .130$; GFI = .97; AGFI = .93.		
Managerial expertise	.90 (9.44)	.67
(.81)	.98 (9.10)	.66
	1.01 (11.45)	.79
	.93 (11.19)	.77
Team communication	.88 (10.17)	.92
(.83)	.77 (8.86)	.76
Team self-control	.89 (5.29)	.85
(.68)	.77 (4.72)	.57
Process Characteristics: Chi^2 (*df*:19) 24.80; $p < .025$; GFI = .96; AGFI = .92.		
task ambiguity	1.02 (11.03)	.78
(.82)	1.10 (10.45)	.81
	.79 (10.16)	.73
role ambiguity	1.15 (9.59)	.68
(.81)	.94 (8.13)	.60
	1.37 (10.42)	.73
	1.54 (12.77)	.86
Project Outcome: Chi^2 (*df*:2) 3.75; $p < .150$; GFI = .98; AGFI = .91.		
Team Performance	1.14 (7.87)	.77
(.76)	1.17 (7.27)	.72
	.73 (6.31)	.63
	.64 (4.90)	.51

Note: All *t*-values greater than 1.96 are significant at the .05 level.

and to test our structural model within the framework of path analysis, estimated using Ordinary Least Square regression. This separation of the measurement and structural model building steps (as opposed to simultaneous estimation) allows us to use the power of full-information estimation methods on a data set whose relatively low sample size would have otherwise made simultaneous estimation impossible. Separate analysis is much in line with the recent recommendations of structural equation modelers who contend that there is much to be gained in theory testing, construct validation, and avoiding spurious results from a two step approach [1; 26]. Since misspecification of a model can lead to interpretational confounding if the measurement and structural modeling occur in a single-step [26], our separation of the measurement and structural model minimizes this problem.

We chose path analysis as the structural modeling analytic technique for this study due to its ability to assess causal relationships and decompose effects into direct and indirect components [8; 28]. The major advantage of path analysis is its ability to derive the relative magnitude of the direct effect and indirect effect through team process of team characteristics on team performance. In order to test our theoretical model, we ran a series of regressions by using the Simon-Blalock technique [4; 8]. Finally, we calculated the ratio of indirect effects of team characteristics on team performance through team process to their direct effect. This analysis allows to examine the direct effect of each of team self-control, team communication, and managerial expertise on performance versus their indirect effect through task ambiguity and role ambiguity.

4. Results

Estimation of the theoretical model (M_t) using LISREL8 and Maximum Likelihood (ML) estimators yielded the parameters described in table 3. Each part of the measurement model yields a satisfactory Chi-squared statistic and all the models have Goodness of Fit Index (GFI) and Adjusted Goodness of Fit Index (AGFI) values greater than .9, thus indicating satisfactory fit to the data [2]. All the parameters of the measurement model show acceptable values with no offending estimates such as negative error variance or low lambdas.

We tested for organizational differences in performance using an analysis of variance. No significant difference in performance was found across organizations ($F_{[14,43]} = 1.602$, $p = .12$). Figure 1 presents the results of the path analysis. The results show that hypothesis 1 regarding the indirect effect of team communication through task ambiguity on team performance is supported. Team communication significantly influences task ambiguity, which in turn significantly influences team performance. Both of these paths are negative, indicating that an increase in team communication leads to a reduction in task ambiguity, which in turn leads to an improved team performance. The direct path between team communication and team performance was not significant thus indicating that the impact of team characteristics is not direct.

Our analysis provides mixed support for hypothesis 2 which affirmed an indirect link through task ambiguity between control (managerial expertise and self-control) and team performance. Team self-control significantly influenced task ambiguity, which in turn was significantly associated with team performance. Thus, an increase in self-control leads to a decrease in task ambiguity which in turn increases performance. Managerial expertise on the other hand did not exhibit a significant link to task ambiguity. Neither constructs showed any significant direct link to performance.

Hypothesis 3 aimed at showing that team communication had a indirect influence on performance through role ambiguity. This hypothesis was supported. Team communication was found to be negatively and significantly related to role ambiguity which in turn was significantly and negatively related to team performance. This finding indicates that increased team communication is associated with a reduction in role ambiguity which in turn is associated with an improvement in team performance. The direct link between team communication and performance was not significant.

Our analysis provides mixed support for hypothesis 4 which affirmed an indirect influence between team control (team self-control and managerial expertise) through role ambiguity and team performance. Team self-control has no significant influence on role ambiguity. Managerial expertise, on the other hand, shows a negative and significant influence on role ambiguity which in turn has a negative and significant impact on team performance. Thus, a high level of managerial expertise leads to a reduction in role ambiguity which in turn is associated with an improvement in team performance. No direct link between either control constructs was found to be significant.

In order to further investigate the validity of the model, we broke down the correlation between team characteristics and team performance into constituent parts representing: direct effect, indirect effect through each of role and task ambiguity, and unanalyzed effects. Reproducing the correlations from these constituent parts provides a powerful test of the path model fit. We found a low level of unanalyzed effects, all below .05, which indicate that the theoretical model accurately represents the observed correlation [4; 28].

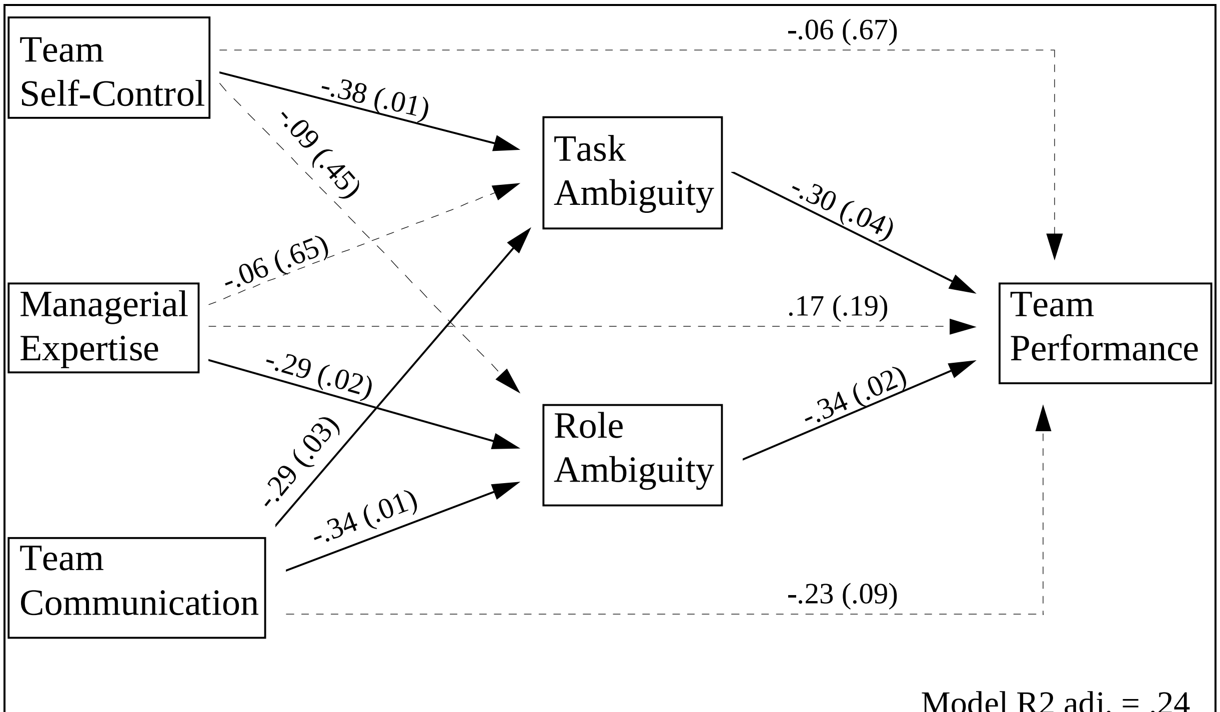

Figure 1: Theoretical Model

5. DISCUSSION

The most critical finding of this study points out that the indirect effects of communication and control through task and role ambiguity are stronger than any of the direct effects. The importance of such a finding is in its emphasis on the difficulties incurred when developing software: significant degrees of task and role ambiguity. We maintain that because software development projects are so complex with high degrees of associated task uncertainty [22; 5] developers experience role ambiguity as such, researchers should take into account the mediating effects of role and task ambiguity. Yet, very little other research has looked at these variables as mediators to team performance. Similar to newer social research in other related fields mediation models may be better able to reflect the complexities of real world problems. Apart from this broad conclusion, the specific paths point to interesting results for researchers as well as managers.

Table 4. Analysis of Direct vs. Indirect Relationships

Antecedent Factor	Self Control	Mgrl. Skill	Team Comm.
Total association with Team Performance (A)	0.06	0.21	-0.02
Indirect effect through Task Ambiguity (C)	0.11	0.02	0.09
Indirect effect through Role Ambiguity (D)	0.03	0.10	0.12
Total indirect effects (C + D)	0.15	0.12	0.20
Unanalyzed effects (A - [B + C + D])	-0.03	-0.04	0.01

For example, our findings suggest a strong relationship between team self-control and reduced task ambiguity provides support to the notion that providing the work team with an increased amount of self-control or work autonomy leads to reduced task ambiguity. There has been a good deal of talk about self-managed teams, this result supports the notion the a more autonomous team is better able to reduce their own task ambiguity.

Likewise, an increase in team communication leads to a better understanding of the task and thus a decrease in task ambiguity. This points to an significant finding that the current research does not address: what type of communication makes the critical difference? Is it communication directly about the task or is it communication in for example problem-solving skills.

This is an important distinction in that we note that increased communication between team members did not directly influence performance. Although not quite significant, increased communication negatively impacts performance and it is only through mediation that we are able to discern the positive role that communication can play in this context. It may be that [31] was correct. Perhaps a good deal of communication on the development team is dysfunctional whereas, communication that reduces role and task ambiguity is seen in a more favorable light. While all of theses points are conjecture at this time, the results point once again to the appropriateness of examining indirect effects.

All three independent variables (self-control, managerial control (expertise) and communication) influenced a reduction in the team's perception of role ambiguity. This means that both the manager and the team member is able to help reduce the negative effects of role ambiguity. This too is an important result in that as developers we often do not want to take responsibility for felt conflicts over a particular job.

The finding that both role and task ambiguity are significantly and negatively related to team performance supports our proposition that team process, in this case team-felt task and role ambiguity are strong predictors of overall team performance during software development design activities. Although other researchers have believed this to be the case, few have studied the impact of these in software development (for exceptions see [3]).

Traditional control models do not explicitly include the manager's expertise. Yet our data indicates that this may be the way in which the manager control's the team -- indirectly through his/ her expert power. It may in fact be more important than the more classic -- the direct intervention of the manager. The manager's expertise may be the essential dimension of managerial control, or at least one that should be considered, when conducting research in the area of software development where it is continually noted that the project manager's expertise -- in-depth knowledge of the task and their general competence in a given technical domain is increasingly important to the success of a development project.

Our model stresses the importance of internal communication in order to reduce work-related uncertainty. Internal communication reduces role ambiguity as expected. The more the team communicates, the more their mutual roles become clear. Internal team communication did not however, reduce task ambiguity as we expected. One explanation for this lack of association may be that our questions on internal communication measured frequency of communication and may not have been directed specifically to the task. Further research will be necessary in order to investigate whether frequency of task related communication will reduce task ambiguity.

A limitation of our research is that we did not study external team communication. It may be that communication with people who are not formal members of the team but are aware of the political workings of the organization can also reduce role and task ambiguity.

Inherent in IS design is a high degree of task ambiguity which will always be experienced by the team due to the complexity and uncertainty of the design task. It is thus exceedingly important for the team to understand how different communication and structuring mechanisms can help reduce task ambiguity. Much effort in IS research has been expended on building tools that will help manage task complexity (CASE, communication software, Integrated Development Environments). Our findings indicate that teams can reduce task ambiguity without tools.

6. CONCLUSION

Past studies of software development performance have stressed the need to use highly skilled personnel or to use mechanical aids to manage project complexity. Other researchers have stressed the importance of team dynamics, managerial behavior, political interactions, control behavior, and conflict resolution. Our empirical observations indicate that: 1) team performance is negatively associated with role and task ambiguity, and 2) teams can reduce both role and task ambiguity by using communication and control strategies.

We believe that software design teams might benefit from a more behavioral and social perspective along with the predominant tools and method view of software design. Results of this research seem to justify further efforts implementing mediation models of IS performance to better reflect the complexity of real world software development.

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