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# Predicting Technical Communication in Product Development Organizations

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*Abstract*

This work explores prediction of technical communication patterns within product development organizations. Our methodology involves first predicting the patterns of communication and then measuring the actual communications to see if the anticipated linkages are realized. We applied this methodology to a commercial product development project in the electronics industry.

In this case study we found that: 1) 81% of all coordination-type communication linkages were predicted in advance; 2) occurrences of frequent communications were more accurately predicted than infrequent communications; and 3) two-way communication exchange was most often observed, even where one-way information transfer was predicted. For the management of product development projects, these results imply that certain aspects of organizational design can be planned by anticipating the technical communication linkages required for project execution. Finally, a critical analysis of our methodology suggests improvements for future work.

# INTRODUCTION

This paper describes a methodology for predicting and measuring technical communication within a product development organization. We applied this methodology to a single product development project in the electronics industry. The results offer insight into the predictability of communications within project-based organizations and provide some basis for the planning and design of organizations.

This work is motivated by the critical importance of product development in today's businesses and the need to better understand communication issues in product development organizations. Successful companies, as observed by Wheelwright and Clark [1992], must anticipate and fulfill customer needs and deliver products to market faster than their competitors. In a fast-paced, global economy, only companies that do this effectively can survive. Our approach to the improvement of product development activities is based on studying the information transfers occurring between members of product development teams. Prior research on product development organizations by Barczak and Wilemon [1991] and Griffin and Hauser [1992] has analyzed patterns of communication and their relationship to the success of projects. The objective of our study is to assess to what extent patterns of communication are predictable in advance in order to enhance planning capabilities for future projects.

## *Background*

Current trends in business have made product development more challenging by requiring geographically dispersed groups to work together. Pine [1993] shows that over the past decade, markets have become more fragmented, reacting to sophisticated and demanding consumers who expect easy access to low-cost products that provide solutions to specific requirements. Companies have responded with multinational product development which often requires designing products in one locality, manufacturing in another, and selling in yet another. It is often no longer desirable to design and manufacture products at the same site, or even on the same continent, since leveraging company assets across the globe is important for companies serving diverse markets [Ghoshal and Bartlett 1990]. The requirement to act globally with new and large product development projects often requires that cross-functional teams divide into several subgroups distributed over a large geographical region.

Product development projects face tremendous challenges in coordinating cross-functional teams because of several barriers to communication within such teams. Barriers can arise from organizational structures, incentive systems, geographical location, cultural differences, leadership styles and project management practices.

### *Communication Patterns in Product Development*

Specific patterns of communication are essential to successful product development. Wheelwright and Clark [1992] argue that communication need not be enhanced everywhere within a project, but improving communication when and where it is supposed to take place affects the success of product development projects. Previous studies of large-scale product development, such as those of Clark and Fujimoto [1991], reveal that successful development relies upon intensive communication between upstream and downstream team members. Dougherty [1987] concludes that higher levels of inter-functional communication occur more often in successful product development projects and diminished communications exist in failed projects.

Patterns of communication are dependent on organizational structure and project type. Katz and Allen [1982] and Tushman [1978] find that members of established project teams communicate less frequently with colleagues outside of their team. Barczak and Wilemon [1991] further show that patterns of communication are dependent on whether the development process focuses on developing an entirely new product or improving an existing one. The results indicate that communication patterns are dependent on the type of project team. Allen, Lee, and Tushman [1980] show that product and process development projects benefit more from good internal communication than do research or technical service projects. Allen [1986] suggests that organizational forms structured around output, such as a cross-functional development team reporting to a project manager, are better suited to facilitate communications required to accomplish project work.

One organizational design recommended for allowing individuals to exchange information more easily is the co-location of team members. Co-location is the placement of cross-functional team members at the same facility and in close proximity to one another in order to increase the performance of the team by breaking down geographical barriers to communication. Co-location of product development teams is recommended by Smith and Reinertsen [1991], and is based on Allen's research of R&D organizations.

Allen's data are compiled from R&D organizations in which respondents were asked with whom they communicate to accomplish work [Allen 1977; Allen, Lee and Tushman 1980]. Allen finds a higher probability of communication between workers in close proximity, while those farther away demonstrate a markedly decreased probability of communicating [Allen 1977, p. 239]. He shows that as separation distance increases, the probability of communication asymptotically approaches a lower bound, so that a pair of individuals located 30 meters apart have nearly the same probability of communication as individuals separated by 250 kilometers. We refer to this well-known result as a "communication-distance" curve. Allen also found a higher probability of communication for individuals connected by an organizational bond (see also Morton [1971]).

### *Types of Communication*

Many researchers [Allen 1986; Greenbaum 1974; Zelko and O'Brien 1957] have defined various types of communications observed in organizations. Allen [1986] discusses two different types of communication which occur in technical organizations such as R&D laboratories. For the purposes of our paper, we define three general types of communication which are applicable to product development organizations and are helpful in explaining our work (Table 1). The first is Allen's coordination-type communication, whereby team members transfer technical information in order to coordinate tasks and conduct their work. The second is Allen's knowledge-type communication, which allows individuals to remain abreast of technical developments in their field and where team members consult with one another, learn, and develop new skills which may or may not directly relate to work on the project at hand. Finally, inspiration-type communications are those which occur to motivate and inspire individuals, and these are generally more managerial than technical in nature [Allen 1992].

| Type of Communication | Description |
|---|---|
| **Coordination Type** | • technical information transfer<br>• task coordination |
| **Knowledge Type** | • consultation<br>• instruction and skill development |
| **Inspiration Type** | • motivation of individuals<br>• managerial affirmation |

Table 1. Three Types of Technical Communication

Our methodology focuses on predicting coordination-type communication, yet all three types of communication occur in the organization we study. This is a confounding effect which we discuss later.

### *Research Questions*

In our communication study, we compare predicted and actual communication linkages. We first predict what patterns of communication are expected to be essential for executing the tasks comprising the product development project. We then measure what linkages are actually established during the execution of the project. Finally, we study the actual communication linkages and determine to what extent they were predictable in advance.

In taking this approach, we attempt to explore the following questions:

- Is coordination-type communication predictable in advance of the project?
- Are frequent communications more predictable than infrequent ones?
- Can we predict the direction of information transfer when communication occurs?

## RESEARCH METHODOLOGY

This section develops a research methodology to analyze predicted and actual coordination-type communications in a product development project. Our approach involves three steps.

1) Through interviews with project team members, we document the information transfers that would require coordination-type communication within the project. We represent these interactions in a predicted-communication matrix.
2) Using weekly questionnaires, we measure the communication which actually takes place within the organization during the execution of the project. We represent the measured communication linkages using an actual-communication matrix.
3) Finally, we compare predicted and actual communication linkages to explore the questions posed above.

Below we describe the research site and then discuss each of the three steps in this research methodology.

### *Research Site*

We studied a product development project conducted at a manufacturer of electrical interconnect technologies. The development process which forms the basis of our case study is that of an electrical connector used to interface computer boards. This particular project was selected because it was large enough to illustrate the complexity associated with coupled, cross-functional teams, yet because of the relatively small overall size and limited duration of the development process, the data collection burden was manageable within a one-year time frame. The core development team consisted of approximately 25 members, not including suppliers, customers, and a host of others involved in related tasks. The working size of the entire project team varied over time, yet never exceeded 50 team members. At any point there were approximately 30 active participants generally arranged into four sub-groups across five separate locations.

The project team faced several major barriers to communication which are common to many product development efforts. The project structure included: 1) four major organizational boundaries; 2) five distinct geographical locations; 3) an extended project team consisting of suppliers, customers, and internal support groups dispersed geographically; and 4) a network of smaller teams consisting of members with cross-functional disciplines. We included all of the team members in our study; however, because we were somewhat constrained in data collection due to logistical considerations, we were not able to directly poll suppliers and customers. We expect that a more comprehensive study which includes these linkages would provide additional insights.

### *Predicting Communication Linkages*

We conducted interviews relying mostly on the core team members, the project manager, and functional managers involved in the project. The team helped us to develop a list of tasks required for the project's execution. We then questioned team members about the types and sources of information required to complete each of their tasks. Questions were limited to identifying the information transfers required to accomplish project work; therefore, we collected predictions of coordination-type communication only. These questions were asked at the beginning of the project in order to identify which communications could be predicted in advance.

The result of these interviews is a task-based project description, which we represent in a square matrix known as a design structure matrix (DSM). The DSM is an analytical tool developed by Steward and adapted by Eppinger that has been used to represent and organize technical tasks in complex product development projects [Steward 1981; Eppinger, et al. 1994]. The philosophy behind the DSM method is that if a problem such as a development project can be represented as a set of individual tasks, then the relationships among these tasks can be analyzed to determine the underlying structure of the project. DSM research has been driven by the increased complexity and importance of product development due to the adoption of concurrent engineering. The DSM has been used as a research tool to study complex concurrent engineering projects [Sequeira 1991; Osborne 1993], to facilitate effective linkages between project teams [McCord and Eppinger 1993], and to model development iterations [Smith and Eppinger 1991].

For our purposes in this research, the DSM was merely an intermediate representation. It provided a mapping of all anticipated technical information exchanges required to complete each project task. However, since we intended to conduct a comparison in terms of communications between individuals, we then related people to each specific task and translated the data into a format representing who needed to communicate with whom. Thus, this new matrix represents a prediction of all potential communications. This transformation is not perfect, however, as multiple team members may have been assigned to any one task, and we do not necessarily expect that everyone involved in two interacting tasks would need to communicate directly with one another in order to complete the task. Thus, the predicted-communication matrix represents the potential for coordination-type communication, yet only a subset of this communication can be expected to take place in reality. Note that the predicted-communication matrix is asymmetric to the extent that the task-based process description predicts one-way information transfers.

### *Measuring Actual Communication Linkages*

After the communication linkages were predicted, the communications during the project were measured to determine to what extent the anticipated linkages actually took place. We assessed the actual patterns of communication during the project through weekly questionnaires distributed to all project team members. The questionnaires were distributed at the beginning of a randomly chosen day of the work week. (See appendix for a sample questionnaire.) The team member completing each questionnaire indicated with whom on that particular day he or she communicated about project-related work. A relevant communication consisted of any topic that was related to accomplishing work on the project. In addition to identifying with whom each person communicated, the questionnaire also asked about the direction of information flow (to/from) and about the mode of communication used (email, face to face, telephone, fax). When there were discrepancies about recorded communication between two individuals, as when one respondent did not indicate that a communication took place, we assumed that the communication did take place and that one individual failed to remember or record the event. While it would have been desirable to conduct data collection on more than one day a week, managers at the study company felt that more frequent data collection would have presented an impediment to product development progress.

Relationships between individuals within organizations have been studied for some time in the field of network analysis [Moreno 1978; George and Allen 1989]. The resulting network structure of dyadic communication relationships is called a communication network. The complexity of manually generating and analyzing large communication networks prompted George and Allen [1989; 1993] to develop a computer-based tool to conduct network analysis. One result of their work is a software tool known as A Graphic Network Interpreter (AGNI), developed at MIT and used in our study to represent and analyze the communication data. Though other similar computer tools do exist [Krackhardt and Hanson 1993], we utilized AGNI since it was adaptable to our special needs in this research.

To compare with the predicted-communication matrix, we constructed an actual communication matrix by aggregating the weekly survey data. In this matrix, the rows and columns represent individuals within the organization, and the data entries determine who communicated with whom during the execution of the project. Since questionnaires were issued randomly once a week, only a fraction of the communication taking place is represented in the actual-communication matrix. We can next explore the actual patterns of communication with respect to the predicted patterns, frequency of communication, and directionality.

### *Comparing Predicted and Actual Communication*

The data collection process described above resulted in two matrices showing the predicted and actual patterns of communication in the project organization. The resulting "comparison matrix" is simply a convenient summary of the predicted- and actual-communication matrices (see Figure 1).

Data analysis began by first examining the pattern of linkages in the comparison matrix, and determining to what extent anticipated linkages actually took place. We examined the direction of actual information flow by aggregating questionnaire data, which could then be compared to the directions predicted. Frequency of communication between each pair of individuals was obtained by accumulating the number of recorded communications over the weekly surveys.

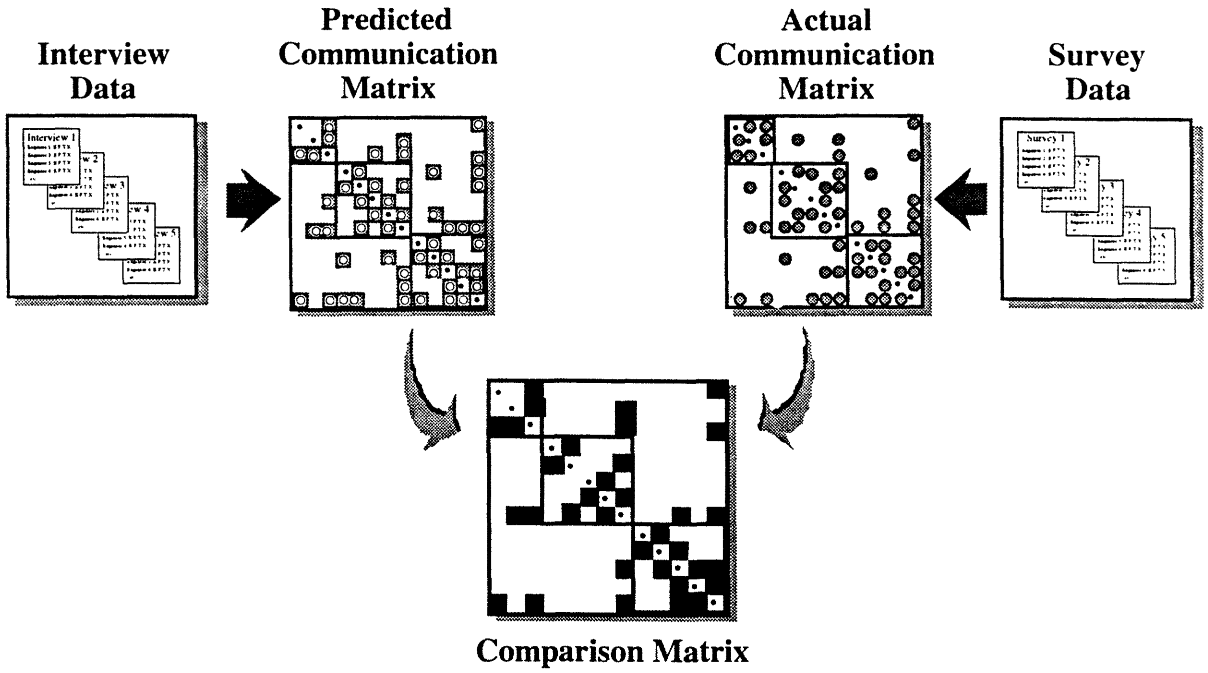



Figure 1. Comparing Predicted and Actual Communications.

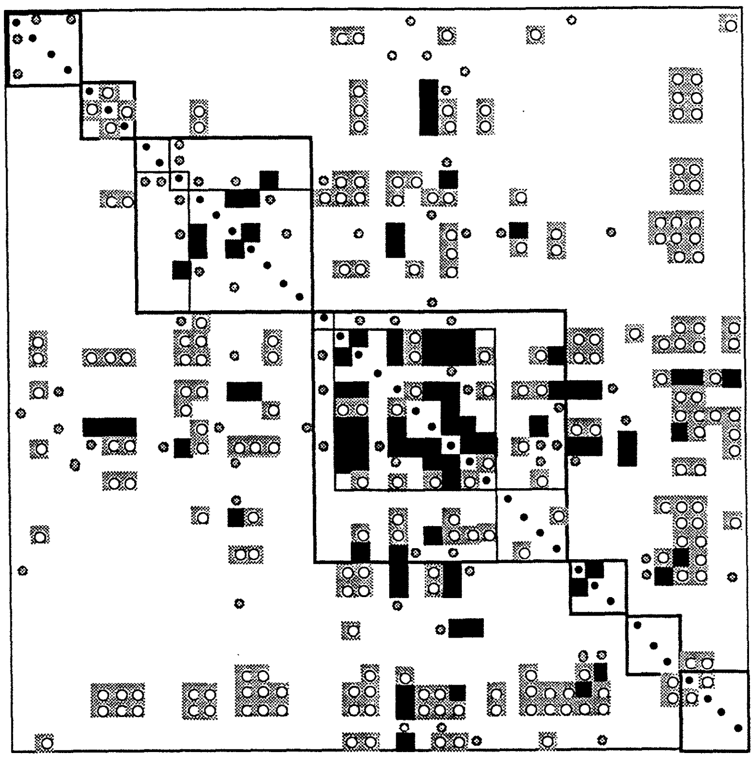
## RESULTS

Using the methods described above, we were able to directly compare predicted and actual communication patterns in the comparison matrix format and to consider the frequency and directionality of the communication linkages. This section presents the results of these analyses.

### *The Majority of Coordination-Type Communications Were Predicted*

Predicted and actual communication linkages are shown together in Figure 2 in the form of a comparison matrix. Each row and column in the matrix represents an individual on the project team. The hollow blocks and solid blocks in the diagram represent the set of all predicted communication linkages. The solid circles and solid blocks represent the set of actual communications. The solid blocks alone represent the subset of the predicted communications that actually occurred. The solid lines forming boxes in the figure delineate separate geographical locations, and the boxes within two of these denote organizational boundaries within those locations.

The existence of hollow blocks in the figure indicates that communication linkages were predicted but not actually observed in the study. In fact, our data reveal many such unfulfilled predicted communications. We believe these are partly due to the reality that some team members did not communicate with others as they should, and partly due to two artifacts of our research methodology explained earlier: 1) The predicted-communication matrix represents all of the potential coordination-type communication linkages derived from the task structure. One would not expect all of these potential linkages to be realized. 2) The actual communications were sampled only one day each week during a portion of the project, so we would not expect to measure all of the communications which actually occur during the project.



Predicted communication

Actual communication

Agreement between predicted and actual communication

Figure 2. Comparison Matrix Showing Predicted and Actual Communication.

The actual communication consists of 81 established linkages, of which 43 relationships (53.1%) were predicted. These linkages consist of exchanges of technical, coordination-type communications. This initial finding suggests that the coordination-type communication flows are somewhat predictable.

To better understand this simple result, we consider two types of analysis to explore the predictability of communications. First, we address the question of whether our prediction of roughly half of the actual communication linkages could be a random occurrence. Second, we probe further to identify the reasons for the unpredicted communications. The former being intended to show the statistical significance of our prediction in this single-project study, the latter is an analysis of the residual error of that prediction.

As a benchmark for statistical comparison, we consider how our task-based prediction of communication compares to the type of prediction that would be available in the absence of any task information. To do this, we computed a probability of communication for each of the communication pairs among the individuals in our study. We made this benchmark prediction based solely on the distances between team members' offices, and using Allen's empirically observed communication-distance curve which provides a function of communication probability versus distance for a group with an organizational bond [Allen 1977, pg. 241]. Given these organization-based probabilities, we simulated the communication patterns that would occur. Over many simulation trials, these patterns could also be directly compared with the actual communication data. We found that this organization-based simulation predicted an average of 23% of the actual organization's communication pairs, with standard deviation of 4.7%. In comparison, our task-based prediction matched 53.1% of the actual data points, more than five standard deviations above the mean prediction based on proximities. We repeated this analysis for the 16-person subset of individuals of the core development team. This second simulation developed communication networks which matched 25% of the actual communication pairs with standard deviation of 6.8%, whereas our task-based prediction matched 58% of the actual communication points.

To explore the reasons why the unpredicted communications (residuals) occurred, we conducted follow-up interviews with all of the respondents who reported unpredicted communication. (These communications are represented by the set of solid circles in Figure 2.) The Pareto analysis shown in Table 2 summarizes the reasons we found for unpredicted communication. This analysis reveals that the majority of the unpredicted linkages comprised two categories: consulting contacts (37.2%), and managerial contacts (39.5%). Consulting contacts are knowledge-type communications, where in most cases we found that individuals were seeking advice or expertise. It is not surprising that these communications were not predicted from the task descriptions, given the unforeseeable inspirations and motivations revealed by examining the nature of such consulting contacts. Managerial contacts are inspiration-type communications which consisted of seeking information, providing encouragement, solving problems, and discussing resource issues. These communications were not predicted because the managerial contacts involved issues not captured by the task-based development process description.

The remainder of unpredicted communications (23.3%) consisted of technical linkages that were not predicted. These were coordination-type communications consisting primarily of engineer-to-engineer contacts that we feel should have been predicted in advance. These interactions may have been overlooked due to errors in our initial data collection process, the inability of team members to articulate their technical activities in advance, unforeseen technical problems or failure of team members to communicate as they should.

Based on this analysis, we conclude that a majority 81.1% (43/53) of coordination-type linkages were predicted.

| Category | % of Unpredicted Communication |
|---|---|
| **Consulting Contacts** (knowledge-type communication) | 37.2% (16/43) |
| **Managerial Contacts** (inspiration-type communication) | 39.5% (17/43) |
| **Technical Linkages** (coordination-type communication) | 23.3% (10/43) |

Table 2. Breakdown of Unpredicted Communications.

***Frequent and Occasional Communication Linkages Were Predicted***

Analyzing the frequency of each communication linkage reveals that nearly all of the frequent and most of the occasional coordination-type communications were predicted. Based on our overall prediction rate of 53.1%, one might expect the same prediction rate within each frequency class. However, Table 3 shows that this is not the case. Comparing our ability to predict communication linkages in each frequency class reveals that the frequent and occasional coordination-type communications were predicted with greater accuracy than the infrequent class. A $\chi^2$ of 15.02 (far exceeding a critical value of 5.99 at $\alpha$=.05) for Table 3 allows us to reject the null hypothesis that we are no more likely to predict linkages in one particular frequency class than another. Such predictability suggests that regularly occurring communication linkages could be reliably planned within this project.

| | Total Linkages | Observed: Linkages Predicted | Observed: Linkages Not Predicted | Expected: Linkages Predicted | Expected: Linkages Not Predicted | $\chi^2$ Component: Linkages Predicted | $\chi^2$ Component: Linkages Not Predicted |
|---|---|---|---|---|---|---|---|
| Frequent | 12 | 11 | 1 | 6.4 | 5.6 | 3.36 | 3.81 |
| Occasional | 11 | 9 | 2 | 5.8 | 5.2 | 1.71 | 1.94 |
| Infrequent | 58 | 23 | 35 | 30.8 | 27.2 | 1.97 | 2.23 |
| TOTAL | 81 | 43 | 38 | 43 | 38 | **$\chi^2$ = 15.02** | |

Notes:
Frequent linkages are those occurring in over 70% of sample occasions.
Occasional linkages are those occurring in 30-70% of sample occasions.
Infrequent linkages are those occurring in less than 30% of sample occasions.
Expected numbers of linkages are based on the average of 53.1% predicted, 46.9% not predicted.
Chi-square statistics are computed as $(expected - observed)^2 / expected$.

Table 3. Analysis of Prediction of Communication Linkages by Frequency

***Bi-Directional Information Transfer Is Dominant***

We explored the directionality of information flow within predicted and actual communication linkages. In our initial data collection, we asked respondents to predict the directionality of each information transfer. Much of the predicted information transfer was anticipated to flow with the progress of the project work (from upstream to downstream tasks in the product development process). We used our survey data to determine the perceived directionality of each information exchange that occurred. In these data, conflicting responses were not uncommon, as two individuals may perceive the directionality of information flow differently for any given interchange. Responses for each established relationship were averaged over each pair's responses from the weekly questionnaires.

Table 4 compares the predicted and actual directionality for the 38 cases where this comparison was possible. The analysis reveals that even when one-way information flow was predicted, two-way information flow most often occurred. In fact, only bi-directional (shared) information flow was predicted reliably a majority of the time, whereas uni-directional flow of information was rarely predicted accurately. Table 4 shows that uni-directional information was predicted accurately 9% (1/11) of the time, while shared information flow was predicted accurately 73% (19/26) of the time. In fact, 64% of the time (7/11) that uni-directional flow of information was predicted, bi-directional flow actually occurred. Perhaps the most interesting result observed here is simply that bi-directional information flow occurred 68% of the time (26/38).

| Predicted Direction | Actual Direction | # of Occurrences |
|---|---|---|
| two way ⟷ | two way ⟷ | 19 |
| two way ⟷ | one way ⟶ | 8 |
| one way ⟶ | two way ⟷ | 7 |
| one way ⟶ | opposite way ⟵ | 3 |
| one way ⟶ | same way ⟶ | 1 |

Table 4. Predicted Versus Actual Directionality of Information Flow.

## CONCLUSIONS

This paper describes a methodology for predicting and measuring coordination-type communication within a product development organization. We compare predicted and actual communications in order to learn to what extent communication patterns can be anticipated. We believe that this study provides a necessary step towards improving the design of organizations. The ability to predict communications may allow managers to implement appropriate organizational structures based on a project's task structure. Future research should extend this work with further case studies before more general conclusions can be made; however, within this limitation, our analysis suggests several interesting observations.

For the product development organization we studied, we were able to predict the vast majority (81%) of the coordination-type communications that were observed. If this result can be substantiated with further case examples, managers may be able to prescribe and define organizational structures to effectively facilitate coordination-type communication. This implies that managers may be able to improve product development by effectively selecting project team members and by creatively delineating organizational boundaries.

Secondly, we found the observed frequent communications to be more predictable than the infrequent ones. This implies that high-frequency communication linkages may be more reliably predicted in advance. With further validation of this result, managers may be able to anticipate strong communication linkages by studying the task structure of the development process. We believe that facilitating strong linkages through appropriate organizational designs would then improve the product development process.

Finally, communication flow was most often observed to be bi-directional, even when one-way communication was predicted. Furthermore, our ability to predict direction of information flow was quite limited. These results suggest that passing information from upstream to downstream activities in product development should be re-conceived as the exchange of information, which includes an important component of feedback from downstream to upstream.

Many product development texts describe the benefits of frequent information exchange between upstream and downstream activities in the product development process [Clark and Fujimoto 1991; Smith and Reinertsen 1991; Wheelwright and Clark 1992].

Results from this study may be particularly relevant to teams that are considering co-location. There are many issues associated with co-location, including: moving expenses, the limited range of viable co-location options due to increased outsourcing, and assignment of team members to multiple projects. Frequently, decisions must be made to co-locate only a subset of the extended development team. Knowledge of which specific coordination-type communications must take place may be able to inform this difficult organization-design decision.

These results may also apply to the concept of "virtual co-location" which is now being considered for many large development projects. Virtual co-location uses emerging technologies to link dispersed members of an organization in order to facilitate communication [Allen and Hauptman 1990; Davidow and Malone 1992]. Indeed new technologies may enhance many forms of communication; however, it remains to be seen which types of communications will be enhanced more readily through information technologies. Since information technology is central to the implementation of virtual co-location, managers may desire to utilize improved understanding of coordination-type communications to determine which information technology tools to implement for which persons within a project network.

While we were able to draw limited conclusions based on our observed patterns of predicted and actual communication linkages, many of our results are speculative since this study represents only a single development project. In order to strengthen the conclusions that might be drawn, it would be useful to conduct studies at several company sites to confirm the robustness of our findings.

Based on the lessons learned from this trial study, this research methodology can next be applied to a larger product development organization where the organizational and communication challenges increase as the complexity of the project increases. Such a study would provide a rich environment for testing hypotheses related to types of communication, organizational structure, barriers to communication, information technology, and project success. Since a major limiting factor of our study was the once-per-week sampling of communication, more frequent sampling would be desirable to more comprehensively compare predicted and actual communication linkages.

Additional research could be focused on the substantial amount of unpredicted communication. We were limited in our ability to analyze the predicted communications that did not actually occur, and this shortcoming would be greatly alleviated by two changes in future studies: developing a more direct mapping of tasks to individuals in the organization, and collecting data spanning the entire project duration. Another important area for future research is into the methods and accuracy of predicting knowledge- and inspiration-type communications, as our study was not designed for this purpose.

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## APPENDIX: SAMPLE WEEKLY COMMUNICATION QUESTIONNAIRE

Survey of Project Communication

This questionnaire is intended to sample work-related communication that you engaged in today. This may well be an unusual day for you, and your communication today may not be at all typical. However, we will sample again on a number of occasions and, therefore, please do not be concerned that today's survey does not capture your typical communication patterns.

Individual responses will not be seen by anyone within your company. The original data will be used only by a small group of researchers at MIT. Only the aggregate analyses and results will be made available to others.

In responding to this questionnaire, please think back over all your activities today. If you communicated with anyone about project-related work today, please circle the appropriate names. Please indicate the medium you used to communicate with each person by circling the appropriate capitalized letter adjacent the name. Also indicate the direction of communication flow by circling the number on the relative scale that represents whether the information conveyed was, primarily required by yourself (1), equally beneficial (4), required by the other person (7), or somewhere in between.

Medium Legend

E = Email F = Face to Face T = Telephone X = fax

Direction of Communication Legend

Info required by yourself Info jointly required Info required by other person

1--------------2--------------3--------------4--------------5--------------6--------------7

Your Name:_______________________ Date:__________ Dept.:_________________

| | | | | | |
|---|---|---|---|---|---|
| *Product Manager* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Manager 1* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Manager 2* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Manager 3* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Engineer 1* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Engineer 2* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Engineer 3* | E | F | T | X | 1----2----3----4----5----6----7 |
| *Engineer 4* | E | F | T | X | 1----2----3----4----5----6----7 |

(etc.)