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Evaluating Communications in Product Development Organizations

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ABSTRACT

This paper develops a novel technique for studying the effectiveness of product development organizations that conduct concurrent engineering. It is commonly argued that to create better products more quickly, the degree of coordination among team members must be enhanced. However, barriers to communication exist across organizational, cultural, and geographical boundaries in dispersed product development teams. In contrast to previous paradigms that encourage co-location and increased communication everywhere, this paper develops a methodology which predicts the important communication linkages and subsequently measures communication flows to determine where and to what extent the necessary transfer of information takes place. We have applied this method to the study of a product development project in industry, enabling us to learn generally about communication patterns in product development and specifically to characterize communication for the product development team studied.

This study documents three major findings: 1) 81% of all technical communication linkages were predicted in advance; 2) communication within co-located teams and across geographic distances was higher than anticipated; 3) two-way communication exchange is typical, even if one-way information transfer is predicted. These results have important implications for the management of large-scale product development projects; namely, that organizational design can be prescribed ahead of time by anticipating necessary communication linkages. We are able to conclude: 1) that essential technical interactions can be planned and do not necessarily require co-location; and 2) that unplanned, informal interactions should be facilitated by co-location of core team members. This paper concludes with a critical analysis of the research method and suggested improvements. While this work is aimed at establishing a methodology, implications are important for the management of new product development.

INTRODUCTION

The goal of this work is to define and explore a methodology for examining communication patterns within product development organizations. The methodology is based on first predicting important patterns of communication and then measuring communication to see if the anticipated linkages exist. The following study applies this methodology to a product development project in industry. The results offer further insight into communication patterns in product development and provide a basis for future research.

This work is motivated by the critical importance of product development in today's businesses and the general lack of specific understanding of 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 quicker than their competition; in a fast paced global economy, only the companies that do this effectively will survive. Our approach to facilitating the critical product development function is based on studying the information transfer between members in the product development organization. Communication studies have been applied to many organizations but little work has been tailored specifically to the product development process. Work on product development organizations done by Barczak and Wilemon [1991], Griffin and Hauser [1992] analyze patterns of communication and relate them to the success of projects. Our focus is to prescribe important communication linkages in a product development organization and then to measure these linkages to see if they exist.

Background

Current trends in business have made product development more challenging by intensifying geographical barriers to communication within the organization. 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 means designing products in one locality, manufacturing in another and selling in yet another. As the case of Motorola [1991] exemplifies, it is often no longer possible or desirable to design and manufacture products in the same building, or on the same continent, since leveraging company assets across the globe is important for companies serving diverse markets. The requirement to act globally with new and large product development projects often requires cross-functional teams divided into several subgroups and distributed over a geographical region [Dean and Susman 1989].

Even though successful product development projects face greater challenges in coordinating large, dispersed cross-functional teams, historical barriers to communication continue to persist. Barriers can arise from organizational structures, incentive systems, geographical location, cultural differences, leadership styles and project management practices. Operating within these barriers is difficult for modern product development. Especially since the practice of concurrent or simultaneous engineering, employed to speed up the product development process, requires increased coordination [Clark and Fujimoto 1991; Clausing 1989; Krishnan, Eppinger and Whitney 1993]. This is because as firms continue to shrink development time through concurrent engineering, tasks must be overlapped more aggressively, requiring much coordination between tasks.

Communication Patterns in Product Development

Successful product development requires smoothing the barriers to communication and enhancing communication when and where it is required. It is not that communication must be enhanced everywhere, rather that specific patterns of communication have been shown to be related to successful organizations. Previous studies of large-scale product development such as the work conducted by Clark and Fujimoto [1991], reveal that successful development relies upon intensive communication between upstream and downstream team members. While 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. Allen, Lee and Tushman [1980] have shown that for R&D organizations, increased internal communication within groups does not correlate to increased project performance, while organizations strongly benefit from communication with other parts of the firm. This may be due to diminishing returns of internal communication where the benefits of communicating more to internal group members does not provide much additional benefit, while even small amounts of additional communication to others outside the group provides greater benefit.

Though research has verified the importance of communication, we believe that it is neither practical nor beneficial to increase communication everywhere. Enhanced communication when and where it is supposed to take place affects the success of product development projects [Wheelwright and Clark 1992]. Certain patterns of communication such as that between project manager and specific subgroups are dependent on the type of work conducted by the team. Barczak and Wilemon [1991] support this by showing that patterns of communication affect the success of product introductions and are dependent on whether the process focused on developing an entirely new product or improving an existing one

In order to study patterns of communication, Allen [1986] has identified three basic types of communication: coordination, information and inspiration. This classification helps to analyze the work content of communication linkages in product development organizations. Coordination-type communication entails information transfer for the purpose of executing tasks and conducting work. Information-type communication includes the exchange of information where learning takes place or where new knowledge is gained, such as receiving instruction on new computer software. Inspiration-type is where new ideas are created but with the same previous knowledge, as in a brainstorming session to solve a problem. While all three types of communication can exist, Allen [1986] shows that some organizational linkages within the project may rely strongly on one or more of these types.

Smoothing Communication Barriers Through Co-location

One practice highly recommended for smoothing communication barriers and allowing team members 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 geographic barriers to communication. Co-location of product development teams is widely recommended by authors such as Smith and Reinertsen [1991], Dean and Susman [1989], largely based on Allen's [1977, p.239] research of R&D organizations. Allen's work shows a higher probability of communication between workers in close proximity, while those farther away have a markedly decreased probability of communicating [Allen 1977]. Figure 1 illustrates Allen's curve relating probability of communication as a function of distance between communicating pairs. This "proximity barrier" curve shows that for separation distances of more than 30 meters, the curve approaches its asymptote, so that dyadic relationships 35 meters away have nearly the same probability of communication as individuals separated by 255 kilometers.

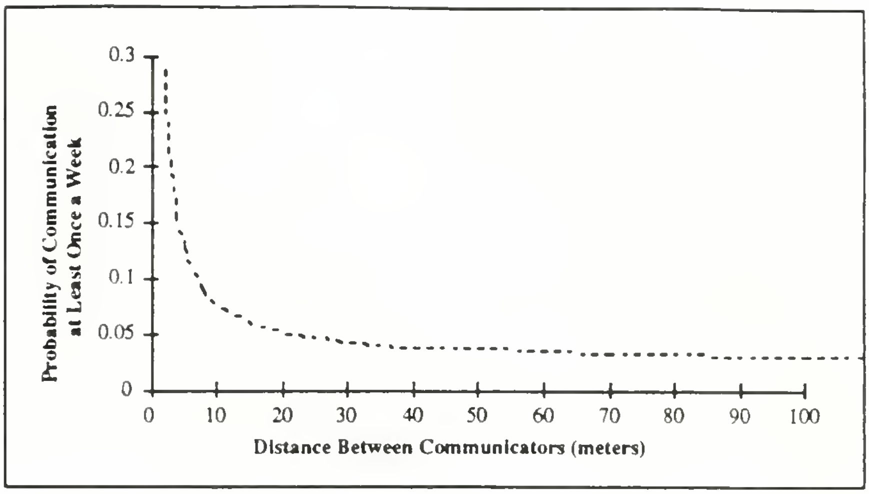


Figure 1. The probability that two people will communicate as a function of the distance that separates them. Taken from Allen [1977, p. 239]. The line represents a regression from data of seven R&D organizations 0-255 kilometers.

Recommending co-location of product development team members based on this information raises several concerns. First, Allen's data are compiled from R&D organizations in which respondents were asked with whom they communicate on a regular basis to accomplish work [Allen 1977; Allen, Lee and Tushman 1980]. The answers are highly dependent on the nature of the work within the organization, and there are distinct differences between basic or applied research and product development project work. While Allen's study is for R&D organizations, the interpretation of R&D included both research and product development, so there is no distinction between the two in data collection. However, R&D organizations are engaged in developing or enhancing technology for future products, while new product development is focused on creating or revising products to be manufactured immediately. We believe these differences in the nature of the work are significant enough to bring into question the potential differences in communication patterns that exist. Recommendations based upon studies of R&D organizational networks involving thousands of respondents across a multitude of projects may not be entirely relevant to a product development team in which 50 to 100 individuals of cross-functional backgrounds are required to work together on a single project.

Furthermore, the proximity barrier has confounding effects which may legitimately explain the reason probability of communication decreases with distance. For example, people in the same geographic location may be organized by work functions so that respondents are surrounded by people they are required to communicate with to accomplish work. It is also possible that people in close proximity communicate frequently with close neighbors, changing the nature of work to include nearby communicators. The proximity barrier fails to differentiate whether nearby communications are required to accomplish work or whether communications across distances are established based on the needs of the project.

Even if co-location proves to be the organizational design of choice, there are several costs associated with co-location that many companies find reduce its attractiveness: 1) The expense of moving a large organization under a single roof may be prohibitive since it can be difficult to obtain a suitable facility and relocate the necessary employees. 2) Increased alliances and outsourcing limit the range of viable co-location options. 3) Some team members may be required to work on multiple projects.

Research Focus

This communication study differs from past research in that we compare the predicted and actual communication linkages in a product development organization. Past approaches measured communication patterns and correlate observed patterns with measures of success. In this study, we first predict what patterns of communication are essential for executing a product development project. We then measure what linkages are actually established. Finally, by comparing the predicted and actual communications, we are able to comment upon the origin and utility of each pattern. Only in this way can we study existing communication and determine if anticipated important linkages take place.

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

- Can strong organizational links be predicted accurately in advance of the development project and do they take place as prescribed?
- Do certain barriers to communication effectively restrict important communication that is supposed to take place, and if not, what are the mechanisms that facilitate cross-barrier communication?
- Does co-location facilitate necessary communication, and is this practice required for necessary communication to take place?
- What organizational forms are required to facilitate communication in product development, and can these solutions be successfully prescribed for a project?

RESEARCH METHODOLOGY

This section develops a novel research methodology to analyze the predicted and actual information transfers in product development. Our approach involves five steps.

1) We define the critical technical information flows which are of the coordination-type communication through interviews with project team members.
2) We use the interview data to plan for future coordinations and represent these interactions in the DSM.
3) We measure what communication takes place within the organization using weekly questionnaires.
4) We use the communication netgraph to represent measured communication linkages indicated from weekly data.
5) Finally, we develop frameworks to compare predicted and actual communication linkages to explore the questions posed above.

Predicting Communication Linkages with the Design Structure Matrix

We represent predicted linkages using the design structure matrix (DSM). The DSM is an analytical tool developed by Eppinger [1991] and Steward [1980], that has been used to organize and sequence tasks in complex product development projects [Eppinger, Whitney, Smith and Gebala 1990; Steward 1981]. The philosophy behind the DSM method described by Eppinger [1991], is that the project can be represented as a set of individual tasks, and 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 simultaneous engineering and design for manufacturing. In an attempt to speed time to market, managers aggressively overlap design tasks, increasing the coordination requirements between overlapping functions. Figure 2 shows the increasing overlapping of tasks in concurrent product development and the need for enhanced information flows. The DSM

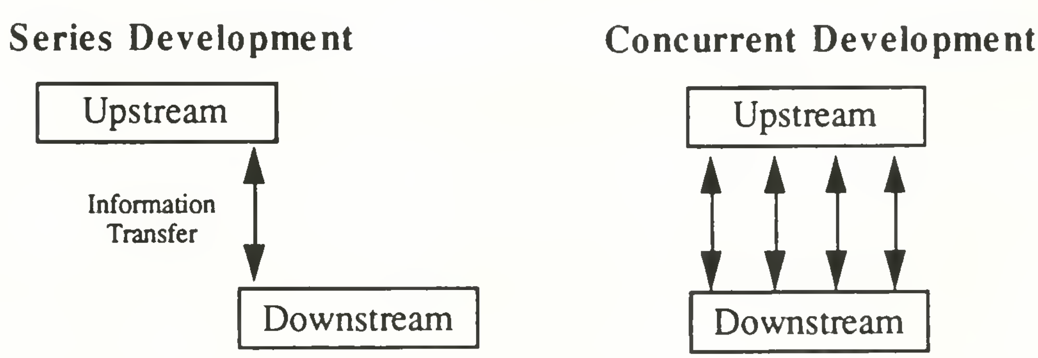


Figure 2. Overlapping of design tasks in concurrent or simultaneous engineering requires increased levels of information exchange as shown by Krishnan et al. [1993].

has been used by Krishnan et al. [1991], Sequeira [1991], Smith [1992] to study complex concurrent engineering projects, by McCord [1993] to facilitate effective linkages between project tasks, and by Osborne [1993] to model development iterations.

In Figure 3, the design tasks for a hypothetical project are shown in the DSM format. Each task in the project is described by a row and a column of the matrix. For each task's row, we place a mark in every column from which the task needs input. Then scanning across each row indicates the informational input required for task completion. Reading down any column then indicates where the task's informational output must flow to downstream processes. For example, row D shows that completion of task D requires information from tasks B, C and E, and reading down column B indicates that information from this task is required by tasks C, D, and G. The objective of the DSM is to plan for the most efficient structure for the development project and to map the information interdependencies between tasks which can facilitate the passing of information between tasks. We depict a set of tasks to be executed concurrently by drawing a block to group these tasks. For more information on the DSM see [Eppinger 1991; Steward 1981; Morelli 1993].

	TASKS:	A	B	C	D	E	F	G	H
A	Determine specifications	•							
B	Design concept	X	•	X	X				
C	Design component 1		X	•	X	X			
D	Design component 2		X	X	•	X			
E	Design tooling			X	X	•			
F	Integrate design & tooling			X	X	X	•		
G	Prototype manufacture		X				X	•	
H	Product test							X	•

Figure 3. Example of a DSM for a hypothetical project. Each mark represents a need for information transfer. The task sequence is depicted by the ordered listing, and concurrent activities are identified by the block grouping tasks in the matrix.

Representing Measured Relationships with the Communication Netgraph

Once the coordinating linkages are predicted, the communications are measured to determine to what extent the linkages actually took place. 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. A typical communication network is shown in Figure 4. Each numbered node represents a person and the lines connecting the nodes represent significant relationships.

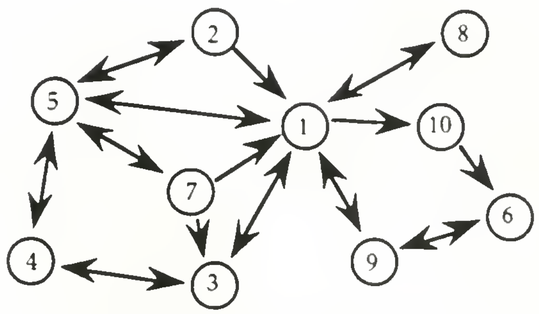


Figure 4. Typical communication network for a small organization.

The resulting complexity of generating communication networks in this manner prompted Allen and George [1989, 1993] to develop another framework in which to conduct network analysis. One result of their work is a computer tool known as A Graphic Network Interpreter (AGNI) which was used in this study to represent and analyze networks. The AGNI format enables researchers to conduct network analysis using a graphical matrix representation of networks called a netgraph. The netgraph is a pictorial representation of networks in which the nodes can be used to represent individuals and the relationships between individuals can be depicted by the presence of a symbol in the matrix linking two individuals. The relational data between individuals can be used to create an array of elements that represent contacts between individuals within the organization. While positions along the columns, rows and the matrix diagonal represent individuals in the organization. The netgraph would be completely symmetrical if for each communicating pair, both members indicated that a significant communication took place.

AGNI is used to analyze the data, represent the networks, and to rearrange the rows and columns so that certain relationships can be highlighted such as the frequency of communication or organizational boundaries within the organization. The use of color or shaded symbols can be used to delineate organizational subsets such as individuals with the same job function or an attribute shared between individuals. Figure 5 shows a netgraph where the rows and columns have been arranged by co-located groups. Individuals in the same immediate workplace are grouped by solid lines. Symbols outside the blocks represent communication linkages bridging individuals in separate groups. The two different tile shades in this case represent either high or low frequency communications.

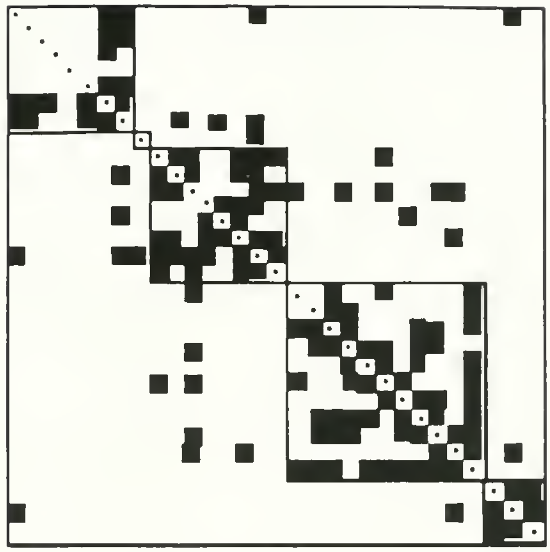


Figure 5. Example of a netgraph grouped by geographical boundaries, with shades denoting frequency of information exchange.

Comparing Predicted and Actual Communication

We use the DSM to prescribe the important flows of information that should take place in product development. The communication netgraph shows the existing patterns of communication among product development team members. Applying these tools to the same product development process allows us to explore the effectiveness of information transfer within the organization.

Although the DSM and communication netgraph each represent information transfer, they are inherently different frameworks, and a transformation mapping between the two is required to conduct comparisons. Figure 6 shows the steps taken in order to compare predicted and actual communication information. The resulting "comparison netgraph" is a summary of the predicted communication from the DSM, and the actual communications represented by the actual-communication netgraph.

The DSM is first translated into the predicted/potential-communication netgraph. Conversion of the DSM into such a netgraph requires each task on the DSM to be assigned a corresponding person or group of people. In order for a communication linkage to be established in the netgraph, the two individuals or groups of individuals must be required to work on a given task together indicated by a mark on the DSM (in this case an 'X'). Confounding effects occur when more than one person is assigned to a single task on the DSM, because it is not known if all or a fraction of the members will actually communicate to accomplish the task. Therefore, the predicted/potential communication netgraph indicated in Figure 6, contains organizational linkages as predicted by the DSM, but not all links need to be fulfilled to accomplish required tasks.

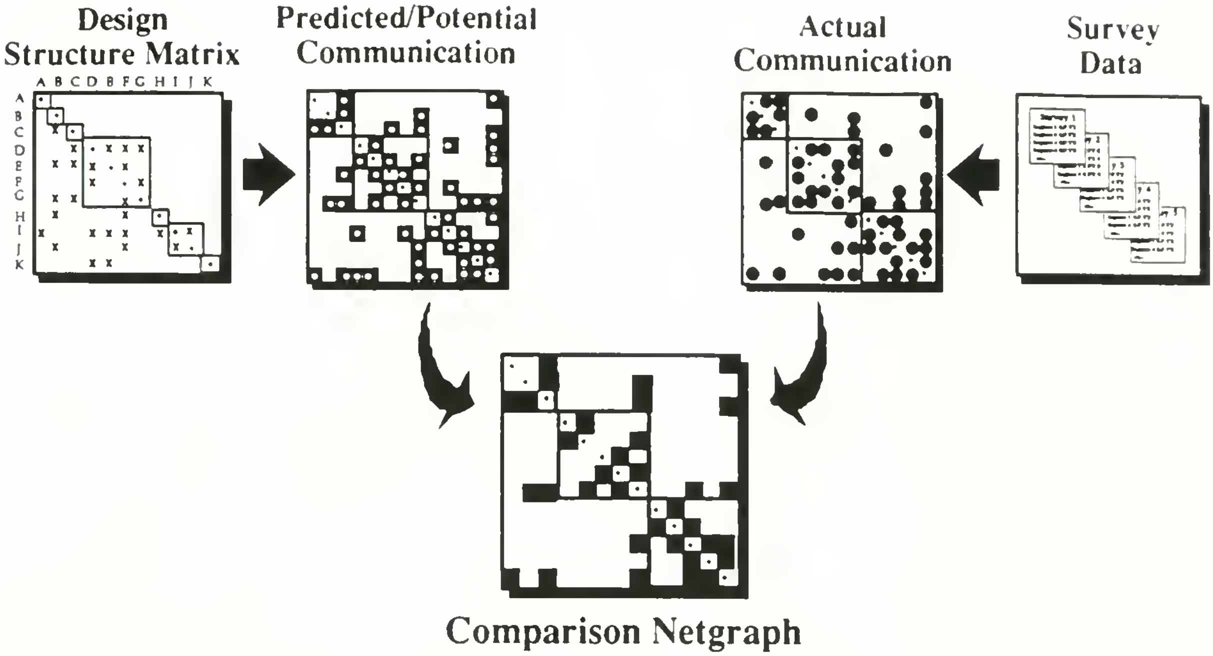


Figure 6. Creating a comparison between predicted and actual communications.

Next, survey data are used to create the actual-communication netgraph. The actual-communication netgraph is obtained by aggregating weekly survey data. No lower threshold limit is set to establish a communication linkage and only one partner was required to indicate that communication took place. Since questionnaires are issued randomly once a week, only a fraction of the total communication is represented in the actual-communication netgraph.

Once the predicted- and actual-communication netgraphs are created, a direct comparison between the two results in the comparison netgraph. This representation depicts the communication linkages that are predicted and those which actually occur. By examining the pattern of linkages in the comparison netgraph we are able to determine to what extent predicted linkages actually take place.

Additional insight into communication in product development organizations can be obtained by analyzing the work content, direction of information flow, and communication frequency of the linkages in the comparison netgraph. Since each linkage involves a pair of individuals on the project, we can conduct phone interviews to determine the general work content of interesting communication linkages. We can examine the direction of information flow by aggregating questionnaire data. We can estimate communication frequency by accumulating the number of recorded communications for the weekly surveys. We can predict communication frequency from the DSM by accumulating the number of anticipated interactions between team members.

Research Site

We applied this methodology to study a major product development project for a manufacturer of electrical interconnect technologies. The company is an aggressive player in the market and uses concurrent engineering on all product introductions. The development process which forms the basis for this study is an electrical connector used to interface computer boards. This particular project was selected because it was large enough to illustrate the complexity of separate cross-functional teams, yet because of the relatively small team size and short duration of the development process, the data collection burden was manageable. The core development team consisted of approximately 25 members not including vendors, customers, and a host of others involved in related tasks. The working size of the entire project team changed over time, yet never exceeded 50 team members. At any point there were approximately 30 active participants. Due to work done by Granovetter [1973] showing the importance of weak communication linkages, we determined that the inclusion of all team members in this study may be relevant, yet we were constrained in data collection as we were not able to directly sample either suppliers and customers.

The major barriers to communication for this project team were: 1) four major organizational boundaries; 2) five distinct geographical locations; 3) extended project teams consisting of vendors, customers and internal support groups dispersed geographically; 4) teams of teams consisting of members with cross-functional disciplines.

Data Collection

Two types of data collection were required for this study. First, we used interviews to predict the important coordination transfers of information and represented these data in the DSM. Next we measured the patterns of communication through weekly questionnaires and represented this in netgraphs.

To identify the important information flows, we conducted interviews relying mostly on critical team members. Most information came directly from the project manager and functional managers involved with the project. We also questioned engineers working on development about their role in the project. Questions were asked at the beginning of the project to plan for important communications. Standard questions we used in planning for information flows and constructing the DSM are shown in Appendix A.

Weekly data sampling as the project progressed consisted of questionnaires distributed to all project team members. The questionnaire was distributed at the beginning of a randomly chosen day of the work week. See Appendix B 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. When there were discrepancies about recorded communication between two individuals, as when one respondent did not indicate that a communication took place, it was 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, the company felt that any more data collection would have been an impediment to product development progress.

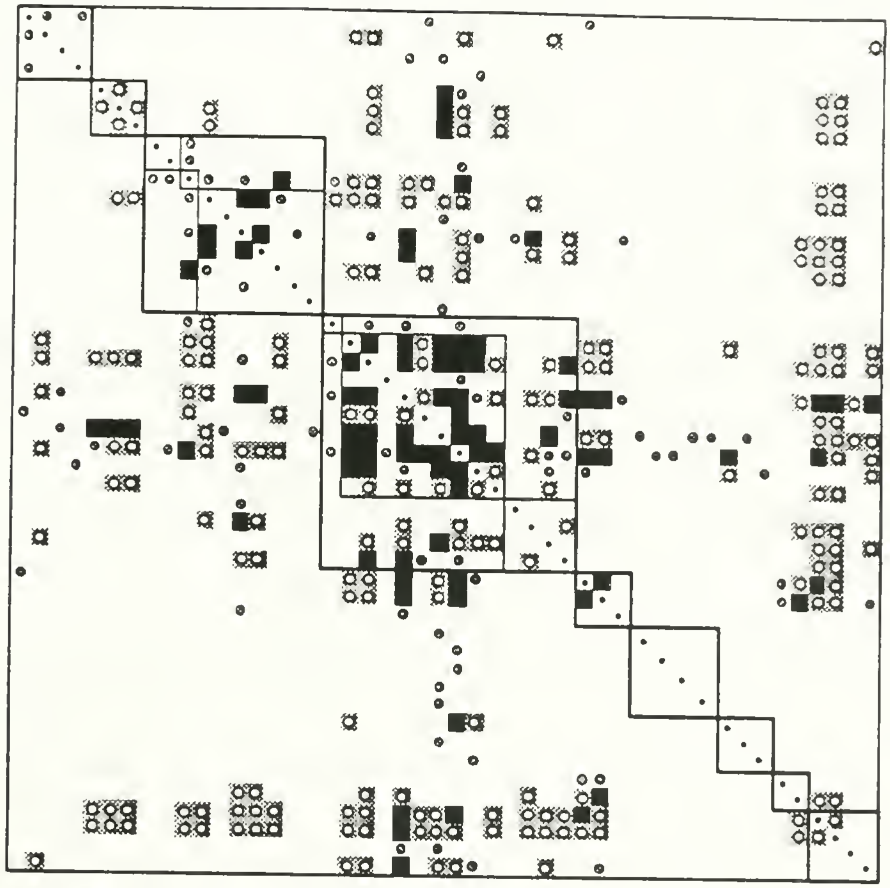
RESULTS

Using the method described above, we analyzed the data by comparing predicted to actual communication linkages. By first converting planned and actual communications into a netgraph of relationships, we were able to directly compare predicted and actual communications by obtaining the comparison netgraph format. Due to the relatively small sample size we were able to analyze the work content of linkages in the comparison netgraph by follow-up interviews. This section presents the results of these analyses.

The DSM Predicts the Majority of Technical Coordination

Planned and actual communication linkages are shown together in Figure 7 on the comparison netgraph. From this summary, we are able to reveal the comparison netgraph and determine that the DSM is reliable in predicting coordination transfer linkages. While Figure 6 showed the predicted, actual and comparison netgraphs separately, Figure 7 shows all three representations in the same netgraph.

This analysis encompasses all of the people who filled out weekly questionnaires as well as those with whom they communicated that did not fill out questionnaires. The solid lines forming blocks in the matrix group linkages in the same geographical region. The thinner lines inside the two large blocks define organizational boundaries within geographical locations. Each row, and column in the netgraph in Figure 7 represents an individual on the project team. Small solid circles along the matrix diagonal graphically represent each individual.



Predicted/potential communication from the DSM

Actual communication from questionnaires

Agreement between predicted and actual communication

Figure 7. Netgraph comparing predicted versus actual communication

The communication linkages predicted by the DSM are represented by hollow blocks. The hollow blocks and solid blocks represent the set of all communication linkages that could be established based on the DSM prediction. While it may be interesting to study the reasons why unfulfilled communications (only the hollow blocks in Figure 7) occur, confounding effects and sampling rate of actual communication make this analysis inconclusive.

The gray circles and solid blocks in Figure 7 indicate the actual communication linkages that took place as sampled from the questionnaires. An actual communication link is established in the netgraph by respondents filling out questionnaires and indicating with whom they communicated on that particular day. No gray circles would exist if all communication linkages were predicted by the DSM.

The set of solid blocks indicates overlapping linkages between predicted and actual networks or the comparison netgraph. Actual communication consists of 86 established linkages, of which 42 relationships (48.8%) were also predicted by the DSM. This suggests that only half of all communication flows are modeled by the DSM, and it is important to explore the reasons why the unpredicted communication (the set of gray circles) occurred. We did this by follow-up interviews with all the individuals involved in unpredicted communication.

The pareto analysis in Table 1 summarizes the reasons we found for unpredicted communication. This analysis reveals that the vast majority of the unpredicted linkages (77.4%) comprised the first two categories; consulting, and managerial contacts. These linkages represent unplanned linkages which are very difficult to predict ahead of time using the DSM. The types of communication content represented with these linkages are for information gathering, idea generation, or problem solving. Consulting contacts were used in seeking advice or expertise from someone inside or outside the immediate location. Managerial linkages occurred due to a number of reasons such as: gathering information, giving instruction, encouragement, problem solving, and resource requests. While it is true that some of these contacts could have been discovered by carefully querying managers ahead of time, we believe that the benefit of actually planning these linkages (to the extent they may be plannable), would be minimal. It is also important to note that these linkages may be numerous but we found that they all are relatively low in frequency. The final category, linkages missed by the DSM, is comprised of engineer-to-engineer contacts that should have been predicted by the DSM but were missed in the DSM data collection process. These interactions could have been missed due to error in data collection or an oversight on the parts of team members interviewed. These were clearly linkages that should have been predicted ahead of time. From this analysis we conclude that the majority 81% (42/52) of "technical linkages" were predicted ahead of time and are therefore plannable. We define "technical links" to include all established links except those managerial and consulting contacts.

Generalized Category	Reason for communication linkage	% of Unpredicted Communication
Consulting Contacts	Internal/external group consulting Unplanned communication (Requires no representation in DSM)	38.7% (17/44)
Managerial Linkages	Manager - engineer contact (20.3%) Manager - manager contact (18.2%) Unplanned communication (Requires no representation in DSM)	38.7% (17/44)
Technical Exchanges Missed by the DSM	Engineer-engineer contact (Requires representation in DSM)	22.6% (10/44)

Table 1. Pareto analysis summarizing reasons for unpredicted communication.

Analyzing the frequency of each communication linkage reveals that nearly all of the high-frequency communication was predicted by the DSM. Table 2 shows an analysis of measured communications by frequency of their observation. We find that only one dyad communicated frequently (at least 8 of the 11 samples) and was not predicted ahead of time. The vast majority of moderate-to high-frequency communicators were predicted by the DSM and more than half of the low-frequency linkages were also accurately predicted. These results indicate that regular coordination linkages can be reliably planned within an organization.

Analysis of communication content of linkages that were both established and predicted reveals that most linkages not predicted by the DSM are for unplannable communications, while linkages predicted by the DSM are assumed to be for the purposes of coordination. For product development, all three types of communication, (coordination, information and inspiration), are important and require facilitation. However, only coordination-type communication is reliably plannable. Unplanned communications such as for information gathering or inspiration occur but were more likely not to be predicted ahead of time. Our interpretation is that information gathering and inspiration-type communication occurs as the immediate needs arise, rather than being plannable. This idea is supported by Fischer [1979] who found that informal relationships which provide access to a variety of experiences appear to be the most valuable sources in situations involving problem solving activities.

Communication Occurrences	Measured Communication Linkages: Predicted by the DSM	Not Predicted by the DSM
Highest (8-11)	11	1
Moderate (4-7)	9	2
Least (1-3)	22	41
TOTAL:	42	44

Table 2. Analysis of measured communication linkages by frequency of their observation and separated into predicted and unpredicted contacts.

Communication within Geographic Boundaries

Comparing communication frequencies of linkages that were both predicted and actually occurred, we are also able to examine the effect of barriers on communication. The geographical barrier was studied in this project, where the majority of team members resided in five separate locations. Due to the fact that the sampling of communication took place once a week, we capture only a fraction of all project communication. The measured communication frequency is approximately 1/5 (one day per work week) of the communications that actually take place. If the predicted communication intensity is low, then it is expected that the actual intensity will be the same or less than predicted intensity. In examining our data summarized in Table 3, 35.1% (13/37) of the linkages have higher than predicted communication frequency. This represents stronger communication linkages than expected from just coordination-type communication.

Actual Communication Frequency	Total Linkages	Intra-Group Linkages	Inter-Group Linkages
higher than predicted:	35.1% (13)	42.1% (8)	27.8% (5)
same as predicted	51.4% (19)	52.6% (10)	50.0% (9)
lower than predicted	13.5% (5)	5.3% (1)	22.2% (4)
TOTAL:	100% (37)	100% (19)	100% (18)

Note: Parenthesis indicate number of communication linkages.

Table 3. Communication frequency of overlapping predicted and actual linkages separated by inter- and intra- group distinctions.

Of these higher than expected linkages, 61.5% (8/13) occur with intra-group linkages. This indicates that higher than just coordination-type communication exists mostly inside groups. In fact, within groups that sit together, 94.7% (18/19) of the linkages communicated at least at the same or more than the coordination level predicted by the DSM. Examining the mediums used to communicate, the vast majority (83.3%) of all communication for the project consisted of face to face communication. These results suggest that higher levels of communication are expected within groups in the same location. It seems reasonable to think of significant inspiration- and information-type communication occurring with contacts in one's immediate surroundings. Even though for cross-functional team members residing in the same location, other barriers exist such as: different functional specialties, training, and technical vocabularies. Grouping team members in the same location significantly facilitates all types of communication.

This information supports the existence of Allen's proximity barrier curve shown in Figure 1 and in Figure 8. In fact, for product development teams, it can be argued that an "organizational bond" exists in which team members are tied to a common goal and recognize an increased need to communicate. Organizational bonds were shown by Allen [1977, p. 241] to increase the probability of communication. Figure 8 compares the product development team curve we obtained to Allen's observation of large R&D organizations.

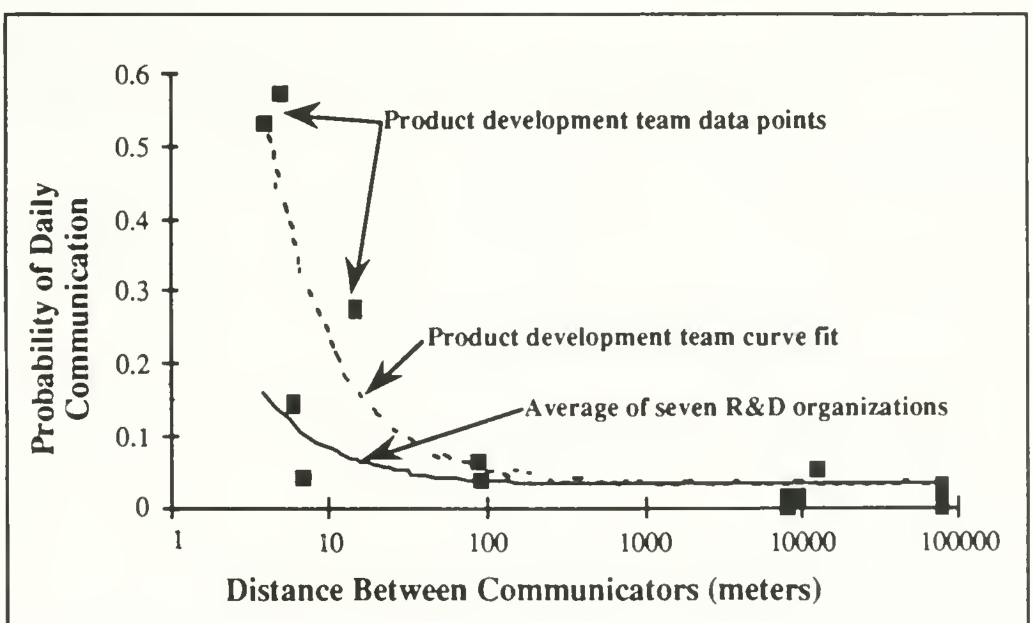


Figure 8. Comparison of product development communication to R&D communication probabilities as a function of distance.

Even though these curves show a decreased probability of communication with distance, it is not clear whether communication between members in distant groups is required to accomplish the goals of the project. It is conceivable that team members that were required to communicate with one another, were co-located together, diminishing the need for communication across geographical distances.

Communication Across Geographic Boundaries

Examining the linkages that span geographically dispersed groups, we compare the planned linkages to the actual linkages and determine if they take place with anticipated frequency. In Table 3, we find that 50% (9/18) of the cases do so at least as frequently as predicted, and 27.8% (5/18) communicate with higher-than-expected frequency. In fact, only 22.2% of the inter-group communication occurred with a lower frequency than predicted, despite the sampling rate of 1 time per week. This indicates that a prevalence of coordination-type communication spans geographical barriers and that the proximity barrier does not significantly limit required communications across geographical distances. It is plausible that geographic barriers are overcome when necessary, especially when team members understand a requirement to coordinate tasks. This does not conflict with our observation that it is much more likely for all types of communication to exist within co-located groups, but suggests that coordination-type communication is prone to occur, despite the lack of co-location. In fact Schuler and Blank [1976, p.126] have postulated that task oriented communication is more satisfying to employees. It is conceivable that perceived benefits of conducting task or coordination work provides a catalyst to facilitate cross-border communication.

In order to predict communication frequency for this analysis, special considerations were taken into account. Since not all tasks require the same amount of interaction for accomplishment, tasks were grouped based on anticipated interaction frequency. A mark on the DSM represented the intensity of the coordination required to complete the task instead of the binary representation previously shown. Table 4 depicts the stratification of tasks, anticipated interactions and requisite DSM value used. Communication frequency was obtained by recording the number of interactions between individuals. Interactions with DSM values of A received higher weighting than with C value interactions.

TYPES OF COMMUNICATION	TASKS	REQUIRED INTERACTIONS	DSM VALUE
Daily / Regular	Work, Design, Development	Several times a day to 5 Times a week	A
Periodic	Coordination, Consultation	5 Times a week to once a month	B
Rare	Consultation, Problem Solving, Learning	once a month to once a project	C

Table 4. Stratification of DSM value by anticipated communication frequency.

Information Exchange Versus One-Way Information Transfer

We also explored the directionality of information flow within predicted and established communication linkages. In many cases information is perceived to flow with the progress of the product, from upstream to downstream in the product development process. In our DSM data collection, we asked respondents to predict the directionality of such information transfer. We then used our survey data to determine the perceived directionality of each information exchange. Conflicting responses were not uncommon since two individuals may perceive the directionality of information flow differently for any given occurrence. Responses were averaged between the dyadic relationships for all responses from the weekly questionnaires.

Table 5 shows the results of predicted and actual directionality. The results of comparing the directionality for overlapping predicted and observed linkages reveals that even when one-way information flow was predicted, two-way information flow most often occurred. Even though directionality can be predicted, only two-way or shared information flow can be predicted reliably, where one-way or directional flow of information is rarely predicted accurately. Upon investigation of Table 5, one-way information was predicted accurately 9.1% (1/11) of the time, while shared information flow was predicted accurately 73.1% (19/26) of the time. In fact, 63.6% of the time (7/11), one-way flow of information was predicted yet two-way flow existed.

Management of development projects should be cognizant that information feedback is associated with most information transfers, rather than interpreted as passing in a single planned direction, say, from upstream to downstream tasks. Many product development texts describe the benefits of passing information from upstream to downstream customers in the product development process, especially to initiate early sourcing [Clark and Fujimoto 1991; Smith and Reinertsen 1991; Wheelwright and Clark 1992]. However it is not clearly recognized that information transfer from upstream to downstream is an opportunity for information feedback as well.

DSM Predicts Direction	Actual Direction	# of Occurences
two way ⟷	two way ⟷	19
two way ⟷	one way ⟶	7
one way ⟶	two way ⟷	7
one way ⟶	opposite way ⟵	3
one way ⟶	same way ⟶	1

Table 5. Comparison of predicted versus actual directionality of information flow.

CONCLUSIONS

The results from this study have important implications for managers of product development projects. Since it has been shown that coordination-type communication can be reliably predicted using the DSM, there is hope that organizational designs can be prescribed ahead of time by methodically planning important communication linkages. For an example of a project where we have attempted to do this, refer to McCord [1993]. Since strong organizational ties can be predicted, management should facilitate pathways of communication for groups of individuals with strong requirements to communicate based on project needs.

Furthermore our results imply that:

- The proximity barrier does not significantly limit coordination-type communications. Decisions on who should be co-located are dependent on the needs for information- and inspiration-type communications.
- It is not necessary to co-locate all team members to enhance coordination-type communications. If only some team members can be co-located, prioritize co-location for cross-functional team members that have needs for all three types of communication.
- If just coordination-type communication is required, facilitate pathways of communication by employing enhanced technologies, or arranging face-to-face meetings for pertinent individuals.

Since the directionality of communication flow is often two-way, passing information from upstream to downstream processes should be re-conceived as having a feedback component as well. Team members are more likely to perceive shared information exchanges or a feedback of information. Managers can facilitate information feedback through enhanced awareness of two-way information exchanges.

Results from this study imply that "virtual co-location" may enhance all types of communication, but coordination-type communication may be enhanced the most. Virtual co-location uses emerging technologies to link dispersed members of an organization to facilitate communication [Davidow and Malone 1992]. However, since communicating across boundaries requires more effort, and people are more likely to conduct planned coordination-type communication across geographical boundaries, this coordination-type communication can be disproportionately enhanced. Since people within the organization rely more upon contacts within their close proximity for information and inspiration, if their needs are immediately fulfilled it is unlikely they will go through the extra effort of using an additional tool to communicate with dispersed team members. Since coordination-type communications were planned beforehand, if the team member is located geographically in another region, the new technology may significantly help in facilitating the required communication.

This methodology has some distinct limitations that should be compensated for on future applications. Due to the sampling rate of once a week, there was a lack of actual communication data. This limited the number of relevant comparisons that we could pursue for this study. There were also some confounding effects associated with assignments of personnel to tasks. More time should be spent delineating responsibilities so that distinct tasks by person can be represented in the DSM. The structure and organization of the project provided significant communication barriers to study, yet more pronounced barriers would provide further areas of opportunity. The establishment of communication linkages proved to be relatively easy, yet analyzing content of communications proved to be difficult and time consuming. More time in future studies should be devoted to analyzing communication content within interesting linkages.

While we were able to draw conclusions based on observed patterns of predicted and actual communication linkages, some of these results are inconclusive, and therefore we identify directions for future study. The methodology of this study can now be applied to a larger product development organization where the complexity of the project increases as the barriers to communication increase as well. Since a major limiting factor of this study is the once-per-week sampling of communication, more frequent sampling is desirable to more comprehensively compare predicted and actual communication linkages. One easy way to do this is to sample more often with each questionnaire covering a period greater than one day but less than a week so that all communications are recorded without the burden of filling out questionnaires daily. In this study we focused on studying the geographical barrier to communication. Other organizations may have more pronounced alternative barriers to communication that require study. Also the effect of planning tools on the product development process can be studied to determine their effect on communication patterns. A twin projects study can be initiated in which one project uses the DSM while another uses traditional methods. The effect of the using the DSM can be observed through communication patterns. Finally, tools anticipated for use in virtual co-location can be studied by applying this methodology to project teams using experimental technologies to determine if enhanced communication is realized based on the needs of the project.

APPENDIX A: Standard Questions Used in Creating the DSM

1. What are the tasks involved with accomplishing your job?
2. What information is required to accomplish your job?
3. From whom do you receive information that is required for your job?
4. What do you do with the results from your work?
5. Who requires information from you to accomplish their work?
6. What percentage of your time is spent on this project?
7. How have the answers to these questions changed over time and how will they change in the future?

APPENDIX B: 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. 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.

Later, we will aggregate the data at a group or department level. Individual responses will not be seen by anyone within your company. The original data will be seen only by a small group at MIT. The aggregate analyses and results will be made available to all who participate.

In answering the 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), by the other person (7), or some number 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

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
Engineer 5	E	F	T	X	1----2----3----4----5----6----7

(etc.)

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