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Product Development: An Empirical Study in the Telecommunications Industry**

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Abstract

Understanding the communication process in product development organizations has been recognized as a key element to improve product development performance. It is particularly interesting to study information exchanges in geographically distributed product development teams because of the highly interdependent nature of design organizations. Additionally, the use of electronic-based communication media has changed how development teams communicate. By studying the way product development teams use various communication media (face-to-face, telephone and email), we assess how the process of exchanging technical information is influenced by factors such as geographic dispersion, organizational bonds, and degree of team interdependence. We develop a theoretical framework that allows us to formulate several hypotheses about how these factors influence both communication frequency and media choice. We use empirical evidence from the telecommunications industry to test our hypotheses. We confirm previous results about the obstructive influence of distance on technical communication. However, we found that such negative effects may be mitigated by other factors such as the recognizing of highly interdependent team members, the existence of strong organizational bonds, and the use of electronic communication media.

1 Introduction

The increasing need to compete in established markets as well as to address new markets in order to sustain corporate growth is adding more pressure onto product development organizations to improve their development performance. Much has been written about process improvement in product development and in particular about the role of effective communication in development teams. Allen [3] pioneered the stream of research dedicated to investigate how effective internal and external communications stimulate the performance of development organizations. Clark and Fujimoto [11] relate successful development in the auto industry to intensive communication between upstream and downstream activities. Wheelwright and Clark [62] emphasize the need to improve communication when and where it improves project performance. Ulrich and Eppinger [56] also emphasize the need to facilitate the exchange of essential information in order to speed up the development process.

The dynamics of current businesses have challenged the execution of product development projects by increasingly requiring more geographically distributed teams to work together [10], [17], [23], [24]. Current practices in product development involve the execution of various stages of the process in various locations around the globe. It is common to encounter firms that design their hardware in one location, write their software in another location, while having their manufacturing facilities spread to yet other locations. Ghoshal and Barlett [22] underscore the importance of developing products in a distributed fashion when serving diverse markets. McDonough III and Kahn [43] present the challenges associated with managing global new product development. Leonard *et al.* [38] present a case study of a geographically distributed software development project, illuminating the problems faced when managing these types of dispersed organizations.

Many researchers have also recognized the tremendous changes occurring in the way current organizations communicate [63]. The use of electronic-based communication media is increasing the number of options distributed development teams have available to coordinate activities, to keep knowledge up-to-date and to spark creativity with non-collocated team members. The widespread use of information technology is reducing the traditional reliance on face-to-face communication in what has been called the “networked organization” [51].

While previous research demonstrating the negative relation between communication and distance is well established [61], [12], [3], [36], [47], less is known about how this relationship

varies with different types of media or communication content nor how distance affects the choice of media used [57]. Utilizing a rich empirical data set collected from interviews in three geographically distributed development teams in the telecommunications industry, we analyze the moderating effects of communication media and content on the relation between communication frequency and distance. In addition, we examine how distance, and other moderating variables, affects the choice of communication media.

In the next section, we present a literature review of relevant research in the area of technical communication in product development organizations. In section three, we formulate several hypotheses about the communication process in product development organizations. In section four, we discuss the study and sample data used in the analysis. In section five, we present and discuss the results of the statistical analyses which test our hypotheses. Section six presents additional statistical analyses to explore whether the type of technical communication influences the use of communication media. We present the conclusions and implications of our findings in section seven and conclude by outlining future research directions in section eight.

2 Communication in Product Development Organizations

Under the information processing perspective organizations are open systems that must process information [53], but have limited capacity to do so [21]. Product development organizations transform a set of inputs (e.g. customer needs, product strategy, manufacturing constraints) into a set of outputs (e.g. product design, production plans). This typically requires that members of a product development team communicate with others, either within or outside the development team, in order to accomplish their development activities. Thus, communication becomes an important factor of R&D performance [2], [35], [16], [27], [29]. As De Meyer noted, “one of the most important productivity problems in R&D is stimulating communication among researchers” [16, p. 49].

Ghoshal and Bartlett [22] reported findings from an empirical study of sixty-six North American and European multinationals indicating that subsidiaries with higher levels of inter-unit communication were more effective in the creation, adoption and diffusion of innovations. In their study of global new product development teams, McDonough *et al.* [44] correlated teams performance with the use of multiple communication mechanisms —what they called an “affiliated set,” consisting of phone, fax, email, teleconferencing, and company databases.

While communication patterns in product development depend on the nature of the project and the organizational structure executing it [9], [45], distance also plays an important role [3], [16]. The barriers to technical communication imposed by distance between team members have been studied so extensively as to be “accepted as an axiom in social theory” [57, p. S3]. Allen’s [3] research on the communication processes in R&D organizations, describing how increasing distance between team members reduced the chances of two team members communicating for technical matters, is probably the best known of these studies in the R&D context. However, there have been several, more recent studies supporting his general findings [36], [18], [32], [41], [57].

Taking exception with much of the previous research on the influence of distance on communication, Van den Bulte and Moenaert claim that “previous research does not allow one to conclude confidently that distance is a major barrier to communication in R&D settings” [57, p. S3]. They note that much of this research lacks contextual realism, internal validity and statistical conclusion validity. Utilizing statistical modeling techniques for sequential network data [60], Van den Bulte and Moenaert examine a “naturally occurring managerial intervention involving the relocation of R&D teams in a leading high-tech company” [57, p. S4]. Although they found that collocation of R&D team members did enhance communication among the members of the team, they also discovered that the communication frequency between R&D and marketing was not affected by the resulting increase in physical distance. “This unexpected asymmetric result suggests that the effect of distance on communication may be moderated by the nature of the communication. Because we measured oral communication broadly, *without discriminating between various media or contents*, directly testing such a conjecture must be left for future research” [57, p. S15, emphasis added].

3 Hypotheses

Similar to Hightower and Sayeed’s [30] “opportunity” and “motivation,” we divide the factors that influence technical communication into two categories: *communication drivers* and *communication barriers*. We define communication drivers as the factors that motivate information transfer between interacting team members, and communication barriers as the factors that hinder the process of exchanging information (see Fig. 1).

Insert Fig. 1 about here

3.1 Communication Drivers

In the organizational communication literature, Daft and Lengel [15] present an integrated framework, based on the concepts of *uncertainty*—the absence of critical and stable information— and *equivocality*—the lack of understanding of a situation—to explain what drives information processing in organizations¹. Similarly, technical communication in product development is required to reduce information deficit—that is, team members deal with unstable information and so must communicate critical parameters as they become known—and to reduce ambiguity—that is, team members deal with imprecise information and so must communicate to define problems or to reach consensus on the solution of a problem. This is similar to the concepts of coordinative information—that used simply to coordinate activities—and innovative information—that used in problem solving—described by Hauptman [28].

The degree of task *interdependence* describes the degree to which tasks require collective action [58]. The greater the degree of task interdependence, the greater the coordinative and innovative information requirements [16]. This is consistent with previous research that has shown that a greater degree of task interdependence leads to greater communication [13], [1]. Allen [5] suggests that the degree of interdependence between engineers' work is directly related to the probability that they engage in frequent technical communication. At the task level, Smith and Eppinger [50] use the strength of task interdependency to identify the activities that require higher effort to coordinate. Loch and Terwiesch [39] present an analytical model to study the coupling of uncertainty, dependence and communication, suggesting that average communication frequency increases with the level of uncertainty and dependence². These models are consistent with the empirical evidence presented by Adler [1] and the numerical approach presented by Ha and Porteus [26].

Thus, we propose the following hypothesis regarding the effects of interdependence on communication frequency:

¹ They were primarily concerned with managerial communication instead of technical communication.

² They model uncertainty as the number of design changes, and dependence similar to the “downstream sensitivity” of Krishnan et al [38].

H1: Communication frequency increases with the degree of interdependence, independently of the communication media used.

Although the majority of technical communication among interacting team members is likely to involve coordinative and innovative information, these are not the only types of communication. Team members may also engage in technical communication for inspiration and general knowledge, not directly related to specific development tasks [45], [5]. Team members can communicate for creative inspiration, managerial affirmation, and to keep up to date with the latest developments in their disciplines. In addition, there is a general tendency for individuals to seek out similar others with whom to communicate—what Van den Bulte and Moenaert [57] refer to as homophily effects.

Organizational structure establishes boundaries within the organization [8], [4], [34]. People within such boundaries are subjected to organizational bonds which promote the development of a language and an identity inherent to the group. Allen [3] found that organizational bonds³ increased the probability of two team members engaging in technical communication. Thus, we expect the following hypothesis to hold true:

H2: Communication frequency is higher between individuals who share an organizational bond, independently of the communication media used.

3.2 Communication Barriers

There are several factors opposing technical communication between members of a product development team. The literature suggests three major types of geographic barriers to the communication process:

- physical distance,
- overlapping working time, and
- cultural/language differences.

³ Other terms are: organizational affiliation, organizational ties.

As stated above, there is considerable empirical research demonstrating the negative effects of distance on technical communication. Allen summarizes his findings about how individual location influences technical communication in the “communication-distance” curve for face-to-face communication in collocated R&D organizations [3, p. 239]. Allen [3] found that the probability of two engineers engaging in technical communication rapidly decays with distance, and suggested that such a communication pattern is *independent* of the medium used to communicate [5]. It is important to note that Allen's results [3], [5] imply that distance is a nonlinear factor, that is, "it is only within the first thirty meters that separation has any real effect on the probability of communication" [3, p. 240]. Allen's work uses distance as a proxy for a wider issue of the influence of architecture on communication. On the other hand, we use distance to capture separation from a global point of view, that is, the relative distance between the facilities where the interacting team members are located.

Although it is not difficult to hypothesize how physical distance presents a direct barrier to face-to-face communication, it is less clear why physical distance would reduce communication independently of the media used. One possible explanation is the concept of the “affiliated set” of communication mechanisms that support each other [44]. De Meyer [16] found in his studies of global R&D that “other than calls for simple exchanges of data, one only calls the people one knows well and sees fairly often.” Thus, one might expect a positive correlation in the communication frequency among various media. As distance reduces face-to-face communication, there is a correlated reduction in the use of other media.

H3: Communication frequency decreases with distance, independently of the communication media used.

In addition, as distance increases, so might working-time differences. With decreasing overlapping working time, synchronous communication becomes more difficult. Under the hypothesis that communication frequency is correlated among the various media, then asynchronous communication would also decrease.

H4: Communication frequency increases with overlapping working-time, independently of the communication media used.

Another possible explanation is that distance is a proxy for other factors such as culture, language and identity. Globally distributed development organizations face differences in language and cultural identity among their team members, and thus homophily—one of the proposed drivers of communication—independent of any organizational bonds that might be shared. Thus, if one could measure differences in language and culture directly, one could identify the effects of these on communication.

H5: Communication frequency decreases with cultural/language differences, independently of the communication media used.

3.3 Media Choice

Although H3 predicts that distance reduces communication frequency across all media, one would expect that the magnitude of the impact would differ. Given the need of physical proximity for face-to-face communication, we would expect distance to have a much greater impact on face-to-face communication than for non-collocated communication.

H6: The rate of decay depends upon the communication media used. Face-to-face communication would exhibit faster decay than non-collocated communication such as telephone and email.

This, of course, has an implication for the choice of media used. Media richness theory [14]—one of the most broadly studied theories about media choice—ranks communication media according to their capacity to process ambiguous information. Specifically, the theory ranks media based upon their ability to provide *feedback*, their capacity to transmit *multiple cues*, their availability to use *natural language*, and their *personal focus*. Accordingly, face-to-face is a richer medium than telephone, and telephone is a richer medium than email. This theory provides a rational criterion to select media to reduce ambiguity. Although some empirical evidence has supported this theory for managerial type communications [54], [33], [48], Markus [40]

challenges the assumption that "richer is better", by showing that even lean media, such as email, can be used for complex communication.

Allen and Hauptman [7] agree with media richness ranking when comparing the bandwidth of certain communication media. However, they also rank media according to their *data-transmission efficiency*. They argue that email is a more efficient medium than telephone and face-to-face from a data-transmission standpoint⁴. By ranking communication media from a data-transmission efficiency standpoint, they provide a rational criterion to select media to reduce information deficit. This criterion is particularly relevant when large amounts of information, such as CAD models, analysis results, and design or manufacturing specifications, need to be transferred.

While "improvements in information technologies will make it easier for technical professionals to communicate ... knowledge is best transferred to engineers through personal contact" [7, p. 282-284]. Other authors have addressed the issue of effectiveness and efficiency of communication media [31], [49]. Warkentin, *et al.* [59] found that although virtual and face-to-face team interactions exhibited similar levels of communication effectiveness, teams using face-to-face interactions reported higher levels of satisfaction with team performance.

Previous work on media choice has focused on determining when individuals choose to use a particular communication medium [15], [54], [20]. Here, we focus on the effects on media choice due to physical separation between interacting team members. Given the fact that face-to-face is a synchronous, collocated medium we expect its probability of being used to rapidly decay with distance, whereas the probability of using an asynchronous, non-collocated medium such as email should grow with distance. When product development teams are distributed around the globe, effects of distance are compounded by the time zone difference between the interacting team members. Its major effect is that simultaneous working time reduces, increasing the efforts to have synchronous communication or simply fast feedback [25], [44]. Telephone (a synchronous, non-collocated medium) may be preferred for distant communication as long as there is simultaneous working time (low time zone difference). Finally, email (an asynchronous, non-collocated medium) will be preferred for long-distance communication. As a result, we formulate the following hypotheses:

⁴ Marril [41] discusses in more detail the efficiency of transmitting digital data.

H7a) The probability of using face-to-face communications rapidly decays with distance.

H7b) The probability of using telephone communication increases, reaches a maximum, and then decays with distance.

H7c) The probability of using email communication increases with distance.

Insert Fig. 2 about here

Geographical separation also implies, in many cases, cultural difference. Language differences, different customs, different ways of referring or treating others have all been recognized as a major barriers to communication [43], [25], [38]. Language differences, in particular, create the need for written-asynchronous communication, which allows interacting parties to take more time to interpret and process the information exchanged [44]. Thus, we formulate the following hypothesis regarding the influence of cultural/language difference on media choice:

H8: The probability of using written-asynchronous communication media, such as email, rather than verbal-synchronous communication media, such as telephone, increases with cultural/language difference.

4 The Study

In the spring and summer of 1995, more than 200 interviews were conducted at 30 facilities, in 13 countries, in three large multinational corporations (MNCs) in the telecommunications industry. These interviews were part of a three-year study of innovation in MNCs conducted from 1994 to 1996. The interviews, which lasted anywhere from one to three hours, were structured with a list of questions, taped and later transcribed. In addition, field notes were taken, and forms were filled out when quantitative data were requested. The transcriptions, field notes and data forms were then used to construct a systematic data set.

Communication data were collected by interviewing members of three different development teams at three different companies within the telecommunications industry. In each interview the respondent was asked to give the name, location and position (including functional affiliation) of the people he/she communicated with during the project. Respondents were asked repeatedly to give us as complete a list as possible. However, on a few occasions, respondents would tire after about two pages (20 partners).

For each communication partner, respondents were asked to rank from 1 (lowest) to 10 (highest) the importance of the communication for the execution of their project-related tasks. Additionally, the media selected to communicate as well as the communication frequency was reported per each interaction. Finally, a brief, qualitative description of the content of the communication was requested.

Given information on the location of the respondent and their communication partners, we estimated the *distance* (in kilometers) between the facilities where individuals were located. Communication partners located at the same facility were given a distance of zero, regardless of the particular “micro-location” of their offices. We also determined the time-zone difference to calculate the *overlapping working time*. *Language differences* were estimated based on the location of the respondent and communicating partners. Examining the title, position description and role in the project of the respondents and their communication partners we determined the level of their *organizational bonds* (either function organizational bonds or project organizational bonds). Since the general content of the message exchanged was also provided for each interacting pair, we grossly estimated the *type of technical communication* associated to each interaction. A detailed description of the variables used in our analysis is provided in Table 1.

Insert Table 1 about here

Some researchers [55], [3] have already attempted to measure information processing by counting communication transactions such as number of memos, number of telephone conversations or face-to-face communications. We also use communication frequency (i.e. number of interactions per unit time for each communication medium used) as our dependent variable.

It is important to note that our metrics for capturing technical communication differ from the ones used by Allen [3]. Allen determined the probability of two researchers engaging in technical communication as a function of distance. Allen determined such probabilities by dividing the number of team members who communicate (at least once a week) by the total number of people available at each distance range. Allen considered all potential pairs in the development organization. Given the scale of our project, it is impractical for us to use the same approach. Instead, we consider only the pairs that actually communicate and their absolute and relative use of communication media to exchange technical information, from the respondent's point of view.

From 255 interviews (respondents) we obtained a total of 829 interacting pairs (dyads) which formed the initial raw data. A screening to eliminate pairs with missing and/or inconsistent information reduced the data set to a sample of 653 interacting pairs of which 485 pairs contained complete information for all the variables. Table 2 shows the descriptive statistics of the sample data analyzed.

Tables 3 and 4 show correlations among the independent and dependent variables, respectively. As one might expect, overlapping working time is highly correlated with distance (-0.945). This will make it difficult to disentangle the two in the analysis. Language difference is also positively correlated with distance, and thus correlated with overlapping working time, but to a much lesser extent (0.599). Note that importance is negatively correlated with distance, but with a lower than expected correlation coefficient (-0.049). Indeed, we were expecting that highly important interactions would take place between more proximate individuals. Also as expected, the frequency of communication in face-to-face is positively correlated with the frequency of communication in telephone, but only slightly (0.245). Email, though positively correlated with face-to-face (0.172), has very little correlation with telephone (0.027). The surprisingly low correlation among the communication frequencies (Table 4) allows us to split the data according to the medium used with much lesser risk of leaving out confounding effects between the dependent variables.

Insert Table 2 about here

Insert Table 3 about here

Insert Table 4 about here

5 Results

Several studies have posited and examined the effects of subsidiary type and MNC strategy on patterns of communication [22], [46]. Although we have not set out to explicitly examine these relationships, we must be aware that firm-level characteristics could have a significant influence on communication. The three multinationals we studied were all in the telecommunications industry, but each was headquartered in a different continent: Europe, Asia and North America⁵.

The European MNC was the most far along in terms of the internationalization of its new product development. Most of its facilities could be classified as *international creators* in the typology of Nobel and Birkinshaw [46]. The Asian MNC was the least internationalized, with many of its facilities evolving from *local adopters* to *international adopters*. The North American MNC was in between, but closer to the European MNC in internationalization of new product development.

The three projects that we studied consisted mainly of software development—though with some, more or less related hardware developments as well. The projects in the European and North American MNCs each involved the development of a global product platform. The project in the Asian MNC involved the development (adaptation) of a product local to the North American market. Fig. 3 plots the dyad-distance profiles for each of the three project samples. It highlights the difference of the Asian distance profile from those of the other two MNCs. In light of this evidence, we ran separate analyses for each firm. However, because the results were not statistically significantly different from the pooled data, the results presented in this section are for the pooled data only.

Insert Fig. 3 about here

⁵ The “North American” corporation had its original headquarters and basic research labs in Canada, but had recently moved the headquarters for the particular business unit that we were examining to the US.

5.1 Communication Frequency

We completed several linear regression models whose results are compiled in Table 5. The first column of this table contains the independent variables. The rest of the columns contain the non-standardized coefficients included in each of the models. Some cells are labeled "excluded" to indicate that such a variable was excluded from the model due to lack of significance.

The dependent variable of the models exhibited in Table 5 is the natural log of communication frequency. This specification of the dependent variable has three important implications.

1. $\ln(\text{communication frequency})$ is closer to a normal distribution, supporting the assumption that the errors of the regression models are normally distributed.
2. The negative coefficients of $\ln(\text{distance}+1.0)$ can be interpreted as the rate of decay of communication frequency due to distance.
3. The coefficients of the other variables included in the models provide an approximation of the percentile change in communication frequency given a unit change in the corresponding variable (i.e. elasticity of the other variables).

Insert Table 5 about here

The first model shown in Table 5 (Total) refers to *total communication frequency*, defined as the summation of all three communication frequencies (i.e. face-to-face, telephone and email communication frequencies) associated with each interacting pair. Models 2-4 are separate runs for each media type. The results clearly support hypotheses H1-H3. That is, communication frequency increases with the *importance of interaction* (H1) and with the presence of strong *organizational bonds* (H2), but decreases with *distance* (H3) across all media.

Not surprisingly, given its strong correlation with distance, the results for *overlapping working-time*, and thus, for hypothesis H4, are mixed. For face-to-face communication, overlapping working time is significant at the 0.05 level, but is not statistically significant for total communication or for the other two media. Given its correlation with distance, we exclude it in model 2'. Similarly, the strong correlation between distance and language difference led us to less explicative models when including this variable. Hence, the results do not explicitly

support the homophily hypothesis (H5) that communication frequency decreases with *language differences* for any media.

By looking at the coefficients of *importance of the interaction* and their standard error for each of the models, and thus, for each medium, we observe no statistically significant difference among them. Furthermore, importance of interaction explains about the same amount of variation for each of the models (media). As a result, we can conclude that the effect of importance of interaction is fairly consistent across all media used.

When analyzing the effects of *organizational bonds* on each of the models, we observe that both telephone and email communication frequencies are much more sensitive to the presence of strong organizational bonds. Additionally, organizational bonds explain a greater portion of variation of telephone and email communications than they do for face-to-face communications.

As we hypothesized (H6), the effect of *distance* on communication frequency is significantly contingent upon the medium used. For face-to-face communication, the rate of decay in communication frequency and the amount of variation in the data explained by $\ln(\text{distance}+1.0)$ is much greater than for telephone and email communications.

5.2 Media Choice

In order to explore the effects of degree of interdependence, organizational bonds and geographic dispersion on media choice, we derive a relative communication frequency per medium by dividing each communication frequency per medium by the total communication frequency associated with each interacting pair. That is, we define the probability that an interacting pair uses a certain communication medium as follows:

$$P(\text{interacting pair using certain medium}) = \frac{\text{Communication frequency of medium}}{\text{Total communication frequency of all medium}}$$

In order to test the effect of *distance* on media choice we ran linear regression models that include *distance* and $\ln(\text{distance}+1.0)$ as independent variables. The results are shown in Table 6 and the resultant curves that describe these models are graphed in Fig. 4. The dependent variable of the models shown in Table 6 is the natural log of the probability of using either face-

to-face, telephone or email, respectively⁶. We included the *p*-values (between parentheses) of the variables included that were not significant.

Insert Table 6 about here

The results presented in Table 6 and graphed in Fig. 4 support hypotheses *H7a-c*. That is, the probability of using face-to-face rapidly decays with *distance*, the probability of using telephone increases, peaks and then decays with *distance*, while the probability of using email increases with *distance*. The results exhibited in Fig. 4 provide empirical evidence of the *substitution effect* on media choice. In general terms, the use of collocated-synchronous media is substituted by non-collocated-synchronous media until the time zone difference effect makes non-collocated-asynchronous media the choice of preference. Given the significant and consistent influence of importance and organizational bonds on communication frequency across all media, it is interesting to note that neither importance nor the presence of organizational bonds is shown to influence media choice.

Insert Fig. 4 about here

As noted previously, distance can be a proxy for language and working time differences. Table 7 presents the new results when we add these later two variables to the model. Again, the results for *overlapping working time* are not significant. However, we see the *language differences* are significantly negatively correlated with the use of telephone and positively correlated with the use of email. The results in Table 7 support hypothesis *H8* that the probability of using written-asynchronous communication media, such as email, rather than verbal-synchronous communication media, such as telephone, increases with language difference.

⁶ Even though the logarithm of the probability does not make the dependent variable more normally distributed in this case, the other two reasons presented in section 5.1 for taking the natural log of the dependent variable justifies its use here.

Insert Table 7 about here

6 Does the Type of Technical Communication Influence Media Use?

Given the relatively low R^2 values for each of the models, it is worthwhile exploring other causal explanatory variables. The most obvious candidate is the content of the communication. A large body of research indicates that certain types of communication would clearly benefit from advances in information technology while others may not [4], [28], [6], [7], [16]. Using the concepts of coordinative information—information used simply to coordinate activities—and innovative information—information used in problem solving, Hauptman [28] argued that coordinative information was more easily transferred via electronic means. Extending these concepts further, De Meyer [16] found that innovative information with high analyzability—that is, where there existed standard procedures to identify, describe and solve the problem—and low complexity could also be more easily transferred via electronic means.

Summarizing and integrating the previous research on communication content [4], [28], [6], [7], [16], [45], [5], we propose the following three types of technical communication:

- *Coordinative*, to reduce information deficit. Team members deal with unstable information and so must communicate critical parameters as they become known.
- *Innovative*, to reduce ambiguity. Team members deal with imprecise information and so must communicate to define problems or to reach consensus on the solution of a problem.
- *Affirmative*, to increase motivation. Team members communicate for creativity, inspiration, and managerial affirmation.

By examining the general description of the content of each interaction provided by each of the respondents, we roughly categorize the type of technical communication between each interacting pair into one of the three above categories. Linear regression models were then run to examine the influence of communication type on both communication frequency and media choice, respectively. The results are exhibited in Table 8.

The models shown in Table 8 are the final models obtained for total communication frequency, probability of using face-to-face, probability of using telephone, and probability of using email. We included two dummy variables on each of the models to indicate which type of communication was associated to each observation. The results show that communication type

does not have significant effect on either communication frequency or media choice. However, this may be due more to the nature of the data than to any real presence or absence of an effect. Note that out of 465 observations, 326 (70%) were coordinative-type interactions (the base case), 60 (13%) were innovative-type interactions, and 79 (17%) were affirmative-type interactions. Also, given the data, we could only give one classification to each interacting pair. Clearly, it is possible that respondents could communicate many different contents with the same individual, and might do so at differing frequencies and using differing media.

Insert Table 8 about here

7 Conclusions and Managerial Implications

While ours is one of many studies on how distance negatively influences communication in distributed development organizations, this study makes important contributions along several dimensions. First, noting Van den Bulte's and Moenaert's [57] comments about "contextual validity", our study examined communication within three global new product development teams. Interviews were conducted during the actual development project, and so did not rely on the ability of respondents to recall details of previous experiences. Second, our study is on a much different scale than many others—notably, Allen's [3] often-cited study of collocated R&D personnel and Van den Bulte and Moenaert's [57] study of the relocation of R&D personnel into another building. Our study is more on the macro scale of "global" dispersion in international development activities. Finally, and most importantly, we not only discriminate the effects of geographic dispersion among various communication media, but also we found that the negative influence of distance can be compensated by high degree of team interdependence, strong organizational bonds, and use of electronic-based communication media. Given the empirical results presented in this paper, a more sophisticated version of Fig. 1 is exhibited in Fig. 5.

Insert Fig. 5 about here

Consistent with previous research, we found that both *interdependence* (as measured by the importance of the interaction) and *organizational bonds* were positively correlated with communication frequency across all media. This supports the hypotheses that interaction criticality and homophily are major communication drivers. The surprising result was that neither of these two independent variables was correlated with media choice. Apparently, people involved in critically interdependent tasks or who share strong organizational bonds engage in a broad spectrum of communication means.

Even when team members were non-collocated, higher communication frequencies were observed for highly interdependent pairs. These results reinforce the importance for managers to identify critical task dependencies in their organizations in order to facilitate intense communication among the team members involved in such interdependent tasks. Furthermore, managers can overcome the negative effects of distance by frequently reminding their team members about the level of criticality of their interdependence.

Conversely, by documenting communication frequencies managers can uncover the underlying structure of development projects as illustrated by McCord and Eppinger [42]. Since the effect of importance of the interaction on communication frequency is fairly consistent across all media used, we can track electronic-based communication transactions to easily identify team dependencies, especially when teams are geographically distributed. Tracking electronic-based communication frequencies can provide an easy and non-disruptive way to obtain the dependency structure⁷ of a development project.

Although we also found supporting evidence for the hypothesis that communication frequency increases in the presence of strong organizational bonds, the surprising finding was the moderating effect of media used. As evidenced by our results, strong organizational bonds have a stronger positive effect on telephone and email communications than in face-to-face communications. Therefore, *organizational bond* is another element that can help managers to overcome the negative influence of distance on technical communication.

As hypothesized, *distance* between interacting pairs negatively correlates with communication frequency across all media. However the magnitude of this effect depends upon

⁷ Refer to Steward [54] and Eppinger *et al.* [20] for an introduction to the concept of design structure matrix and its applications to management of complex product development projects.

the medium used to communicate. Face-to-face communication frequencies rapidly decay with distance while telephone and email communication frequencies decay at slower rates.

When we analyzed the *propensity* to use each of the three media, we found that the use of face-to-face communication is substituted by telephone and email communication when distance increases. Furthermore, our empirical evidence shows (see Fig. 4) that the relative use of telephone communication starts to decay after around 3000 kms, possibly because time-zone difference makes synchronous communication more difficult to accomplish.

Exploring this further, we found that team members located in countries that do not share the same first language show higher probability of using email communication than telephone communication. This supports the hypothesis that people with *language differences* prefer using written, asynchronous communication media, such as email, rather than verbal, synchronous communication media, such as telephone. We recommend managers to identify whether there is a significant language difference between team members involved in critical interactions in order to facilitate asynchronous, written communication.

In summary, relative location of interacting team members influences both communication frequency and media choice. Even if face-to-face communication can be substituted by other electronic-based communication such as email, instant messaging, or video-conferencing, managers should be aware that communication frequency tends to decrease with distance, independent of the media used to communicate. However, managers have other elements, such as team interdependence and organizational bonds, to mitigate the negative effects due to geographic dispersion of development organizations.

8 Limitations and Future Research

The fairly large size of our sample and the diverse nature of the projects examined offer encouragement as to the general nature of our findings. However, like most empirical research, there are significant limitations in our study. Our unit of analysis is the interacting pair. We do not attempt to describe how distance affects the propensity to communicate, only the frequency of communication and relative frequency of media use *given* that two people communicate. Also, our study is cross-sectional, not longitudinal. Thus, the standard caveats apply in drawing conclusions as to situations where one or more of the independent variables are adjusted due to managerial control.

The nature of information technology is changing at an incredible speed. At the time of the field study (1995), despite the fact that all three MNCs were themselves at the confluence of the merging technologies of computer and telephony, none of the development teams used, to any significant extent, emerging communication media such as video-conferencing, desktop conferencing or other “intra-net-based” technologies. Thus, our study is mainly limited to the three primary forms of communication used at the time: face-to-face, telephone and email. More research needs to be done to understand better the trade-off between media richness and data-transmission efficiency of the various communication media now widely available for development teams.

Furthermore, our study did not effectively examine the moderating effects of the content of communication. Clearly, some types of content are better suited to distant-communication than others. It would be useful to examine whether distance reduces communication frequency across media *and* content, and whether content has a significant influence on media choice.

Finally, we have not studied in detail the effect of barriers due to information technology differences. Our results emphasize the importance of minimizing such barriers between critically interdependent team members. Communication barriers due to information technology differences (such as different availability and accessibility schemes, different levels of familiarity with the systems, and incompatible information systems) have to be overcome to facilitate electronic information transfer between interdependent team members. An interesting stream of future research is to study the various effects imposed by these types of communication barriers.

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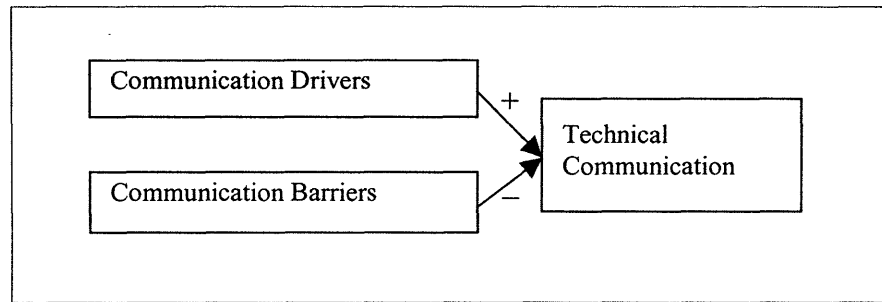


Fig. 1. Factors that influence technical communication

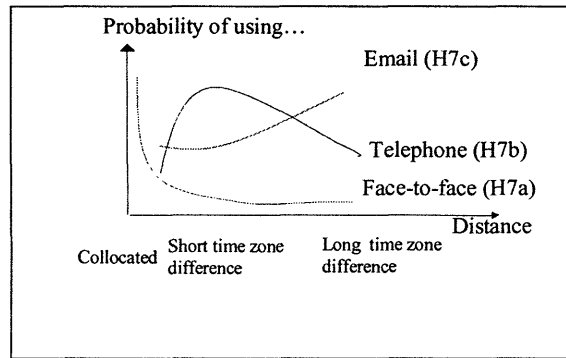


Fig. 2. Effects of distance on media choice (*H7*)

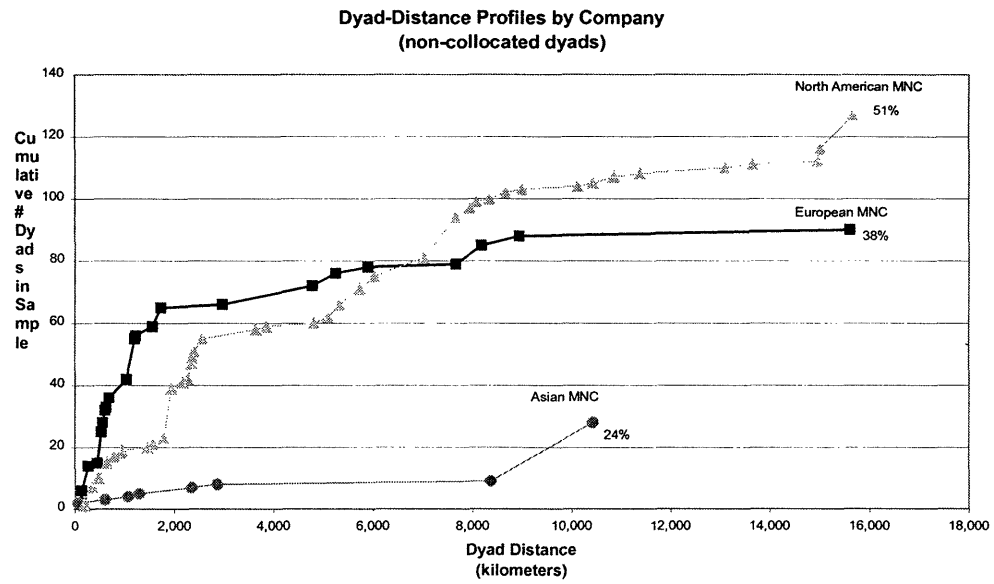


Fig. 3. Dyad-distance profiles for each of the three project samples

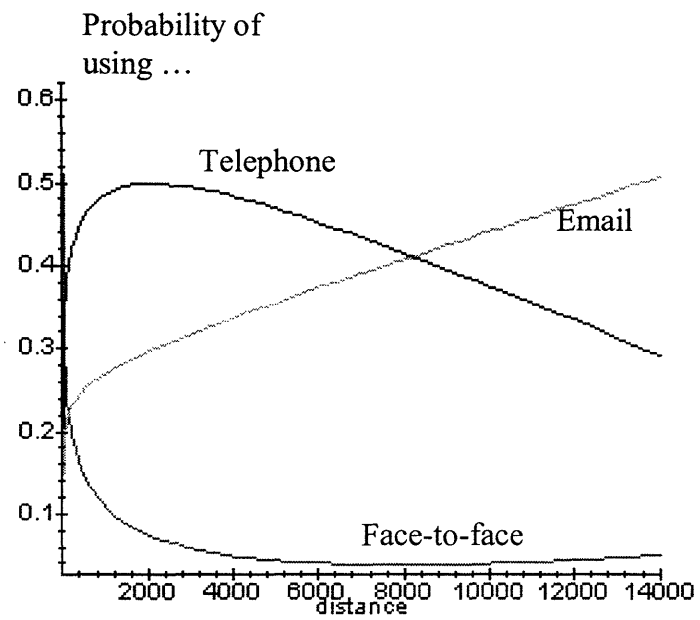


Fig. 4. Distance-based linear regression results

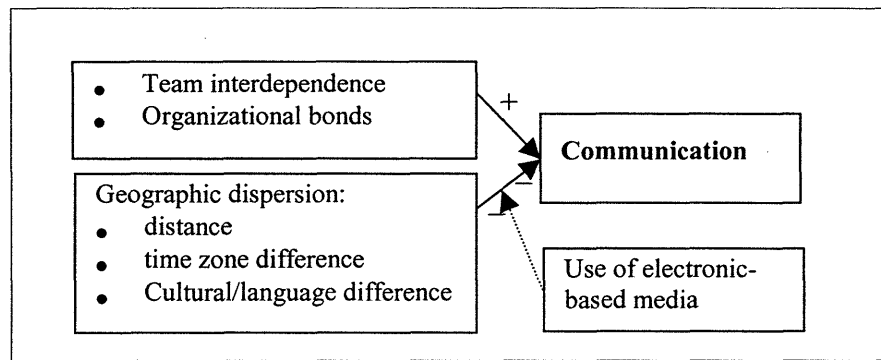


Fig. 5. Summary of results

Table 1. Description of variables used in the analysis

Metric	Description
<i>Importance of the interaction</i>	Scale metric that measures the level of criticality of the interaction from the respondent standpoint. It assesses the degree of task interdependence associated to each interacting pair. A scale from 1 to 10 was used (1=low importance, 10=high importance).
<i>Organizational bonds</i>	Binary metric to capture the level of organizational affiliation between interacting parties. 0=weak organizational bond such as different organizations, different tasks, different professional background. 1=strong organizational bond such as same organization, similar tasks, similar professional background.
<i>Distance</i>	Distance (in kms) between the cities where each of the parties was located.
<i>Overlapping working time</i>	Number of hours in which both parties would be in their office simultaneously (assuming working hours to be from 9 am to 5 pm).
<i>Language difference</i>	Binary variable. 0=same native language. 1=different native language.
<i>Communication frequency using certain communication medium</i>	Number of interactions per week using certain communication medium (face-to-face, telephone and email).

Table 2. Descriptive statistics

	IMPORTANCE (1-10)	ORG. BONDS (0/1)	DISTANCE (kms)	LN (DISTANCE+1)	OVERLAP TIME (hours)	LANGUAGE DIFF. (0/1)	FACE-to-FACE FREQ (#/week)	TELEPHONE FREQ (#/week)	EMAIL FREQ (#/week)
Mean	6.94	0.476	1,922	3.023	6.68	0.222	1.325	0.574	0.935
Maximum	10.0	1.0	15,658	9.659	8.00	1.0	25.0	20.0	35.0
Minimum	1.0	0.0	0.0	0.000	0.0	0.0	0.0	0.0	0.0
Std. Dev.	2.36	0.4999	3,754	3.924	2.48	0.416	2.279	1.584	3.105
Skewness	-0.569	0.0949	2.157	0.602	-1.708	1.333	4.061	6.934	7.663
Kurtosis	2.495	1.009	6.862	1.496	4.492	2.777	32.003	68.349	71.424
Jarque-Bera	31.36	80.83	677.6	75.1	280.7	144.7	18332.0	90188.7	99359.9
Observations	485	485	485	485	485	485	485	485	485

Table 3. Correlations between the independent variables

	IMPORTANCE	ORG. BONDS	DISTANCE	LN (DISTANCE+1)	OVERLAP TIME
IMPORTANCE	1.000				
ORG. BONDS	0.101	1.000			
DISTANCE	-0.049	-0.088	1.000		
LN(DISTANCE+1)	-0.116	-0.075	0.751	1.00	
OVERLAP TIME	0.051	0.096	-0.945	-0.767	1.000
LANGUAGE DIFF.	-0.052	-0.007	0.599	0.714	-0.554

Table 4. Correlations between the dependent variables

	FACE-to-FACE FREQ	TELEPHONE FREQ
FACE-to-FACE FREQ	1.000	
TELEPHONE_FREQ	0.245	1.000
EMAIL_FREQ	0.172	0.027

Table 5. Regression results for communication frequency [†]

Independent Variables	Model 1 (Total)	Model 2 (Face-to-face)	Model 2' (Face-to-face)	Model 3 (Telephone)	Model 4 (Email)
Constant	-0.916***	-2.463***	-1.239***	-1.505***	-1.495***
Importance	0.191***	0.199***	0.200***	0.161***	0.184***
Organizational bonds	0.402***	0.155***	0.341***	0.678***	0.653***
Distance	excluded	excluded	excluded	excluded	excluded
ln(distance+1.0)	-0.117***	-0.199***	-0.254***	-0.075***	-0.064***
Overlapping working time	excluded	0.305**	excluded	excluded	excluded
Language difference	excluded	excluded	excluded	excluded	excluded
N	485	298	298	213	224
Adj. R^2	0.290	0.452	0.445	0.213	0.260

[†] communication frequency = $e^{(\alpha_0 + \alpha_1 \cdot \text{importance} + \alpha_2 \cdot \text{organizational bonds})} \cdot (\text{distance} + 1.0)^{\alpha_3}$

* <0.1; ** <0.05; *** <0.01

Table 6. Results for the effects of distance on media choice

Independent Variables	P(face-to-face)	P(telephone)	P(email)
Constant	0.476***	0.138***	0.118***
Importance	-0.002 (0.696)	-0.001 (0.859)	0.005 (0.251)
Organizational bonds	0.034 (0.103)	-0.023 (0.293)	-0.027 (0.212)
Distance	6.96E-6 (0.113)	-1.88E-5***	9.97E-6**
ln(distance+1.0)	-0.055***	0.040***	0.016***
N	485	485	485
Adj. R ²	0.427	0.173	0.132

*<0.1; **<0.05; ***<0.01 (*p*-values within parentheses)

$$\text{probability of using certain medium} = e^{(\alpha_0 + \alpha_1 \cdot \text{distance})} \cdot (\text{distance} + 1.0)^{\alpha_2} - 1.0$$

Table 7. Results for media choice with language and working time

Independent Variables	P(face-to-face)	P(telephone)	P(email)
Constant	0.462***	0.122***	0.153***
Importance	excluded	excluded	excluded
Organizational bonds	0.033 (0.110)	excluded	-0.035*
Distance	excluded	-1.66E-5***	2.15E-6 (0.224)
ln(distance+1.0)	-0.046***	0.054***	excluded
Overlapping working time	excluded	excluded	excluded
Language difference	-0.054 (0.117)	-0.199***	0.269***
N	485	485	485
Adj. R ²	0.429	0.222	0.239

*<0.1; **<0.05; ***<0.01 (*p*-values in parentheses)

Table 8. Linear Regression Results (effects of communication types)

Independent Variables	Total Communication Frequency	P(Face-to-face)	P(Telephone)	P(Email)
Constant	-0.826***	-0.483***	0.115***	0.145***
Importance	0.185***	excluded	excluded	excluded
Organizational bonds	0.385***	excluded	excluded	excluded
Distance	excluded	excluded	-1.71E-5***	excluded
ln(distance+1.0)	-0.117***	-0.050***	0.054***	excluded
Overlapping working time	excluded	excluded	excluded	excluded
Language difference	excluded	excluded	-0.196***	0.287***
Innovative-type	-0.059 (0.712)	-0.012 (0.674)	0.021 (0.508)	-0.020 (0.517)
Affirmative-type	-0.091 (0.527)	-0.005 (0.867)	0.019 (0.519)	-0.010 (0.726)
N	465	465	465	465
Adj. R ²	0.285	0.425	0.223	0.226

*<0.1; **<0.05; ***<0.01 (*p*-values between parentheses)