The 9th International Symposium on Automation and Robotics in Construction June 3-5, 1992 Tokyo, Japan

Diffusion of Construction Technology: A Communications Approach

Julie Wald and C. B. Tatum
Department of Civil Engineering
Stanford University
Stanford, California 94305-4020 U.S.A.

ABSTRACT

It is widely recognized that more technologies are created than implemented. To better reap the benefits of development, we should look into the dynamics of the diffusion process. Interpersonal communication fundamentally impacts diffusion, the process by which people become aware of and decide to use new technologies. Communication network techniques can be used to map and analyze communication patterns and their impact on knowledge, attitude, and use of technologies, over time, and to identify critical roles and their function in the diffusion process. This paper reports on the first phase of an investigation of the diffusion of new technologies in Japanese and U.S. construction companies. Preliminary interview results, combined with summaries of background research, yield a plan for future work. Increased understanding of the communication patterns and key roles influencing diffusion from this investigation will be used to develop managerial strategies for improving the diffusion of vital new construction technology.

(1) INTRODUCTION

In a major study of an industry by its dissatisfied customers, the Business Roundtable[9] found that the U.S. construction industry is far less progressive than many other major industries in developing and adopting new technology. They concluded that this situation was one of the reasons for the rapid increases in U.S. construction costs. The National Research Council also found that inadequate R&D and the slow adoption of new technology have been major factors influencing the productivity problems of the U.S. construction industry. According to Seaden[32]: "Although the industry is very creative, most construction projects do not use state-of-the-art knowledge or up-to-date technology. Much more is known than is presently used in construction projects."

In 1986, Japanese construction companies invested 15 times more than their U.S. counterparts on research and development (R&D)[37]. While U.S. construction firms rely on proven technologies, Japanese companies emphasize the use of new technology for strategic advantage and the solution of technical and social problems. To perform R&D, the top six Japanese firms spend about 1% of total contract volume annually and employ around 1000 people[36]. In order to harvest the fruit of these investments in R&D, new technologies need to be transferred to the construction site. In this project, *diffusion* is defined as the process by which people become aware of and decide to use new technologies. In both the U.S. and Japan, we need to look deeper into the dynamics of the diffusion process in order to reap the benefits of technological development.

Manufacturing studies of R&D management emphasize the need for interaction between developers and users of new technology to enhance the development and implementation processes[2,21,35,38]. Construction researchers in large Japanese companies have a greater opportunity for interaction with potential users of new technology than their American counterparts, however, in construction, "researchers and builders are separated by differences in outlook, values, and culture."[32]. A study of scientists and engineers in Silicon Valley computer companies identified the need for *liaisons* who could "translate" for different subgroups[14]. In addition to linking people across organizational boundaries[8], informal communication processes can serve decision making under ambiguity[18,19].

This paper describes a research plan using an analysis of communication patterns to describe roles and organizations fostering diffusion of construction technology in U.S. and Japanese firms. By comparing Japanese and U.S. firms, the research will yield significant new insights to improve management of the diffusion process. The paper reviews the background of diffusion and innovation research in construction and other industries, describes network analysis techniques, explains the research approach, and anticipates results. Accelerating the diffusion of automation technology promises major benefits for design and construction. The research described in this paper will assist in realizing this goal.

(2) BACKGROUND LITERATURE

2.1 Diffusion

This investigation will focus on the communication patterns and roles accompanying the diffusion of new construction technologies. *Communication patterns* are defined as prevalent interactions between people and *roles* as positions of individuals relative to other people and the expectations about their behavior[34]. This emphasis is in accordance with a major theme in diffusion literature: "...that *communication* is the basic process by which people become aware of new things and decide to use them; therefore, the dynamics of the communication process are important to understanding innovative behavior"[34].

The aspects of diffusion to be considered are: *knowledge* of the technology, *attitude* toward using the technology, and *use* of the technology. Björklöf[4] reported that while construction sites were important settings for evaluating and diffusing innovations, dissemination of information about new technologies was primarily a corporate function. Knowledge can be measured as name, purpose, alternatives, and capital and operating costs and savings of the technology. Attitude toward use assumes prior knowledge and that decision makers have developed opinions about the merits of potential use, but have not yet reached a decision point for the actual implementation. For studies of "top down" or *authority* decisions, attitude toward the innovation may be a more appropriate dependent variable than actual use due to the long-range effect of organizational members' attitudes on continued adoption[29].

Diffusion is a *process* that evolves over time and includes interactions between individuals and groups of individuals within and between organizations. Longitudinal studies are necessary to adequately consider the causal relationship between informal communication structure and diffusion[28]. To manage multiple levels of analysis, diffusion researchers have been encouraged to use network analysis, described below[27].

2.2 Roles and Construction Innovation

As an extension to innovation research emphasizing the importance of individuals, U.S. construction innovation researchers identified several key roles for innovation in construction. Examples of both process and product innovations exhibited roles identified in other industries: management, commercial, and technical champions, and technological gatekeeper[33]. In addition, many of the projects included an integration champion who coordinated the efforts of team members[23]. Due to the disparate backgrounds of researchers, developers, promoters, and users of construction technology, the integration champion fulfilled a liaison role. Liaisons and their function within the overall social structure can be identified and analyzed using network analysis, described in the following section.

Regarding automation technology for design and construction, several firms have created new organizations to foster development and effective use. These range from the major research laboratories in Japanese firms to software development projects within U.S. engineering and construction firms. Japanese firms actively consider user needs in the definition of research projects and include funding for implementation in research projects[22]. This approach assigns responsibility and provides resources for diffusion. In U.S. firms, R&D managers are often responsibile for implementation; successful innovations have generally required at least one type of champion. In both the U.S. and Japan, the roles and communication patterns are not well understood.

2.3 Network Analysis

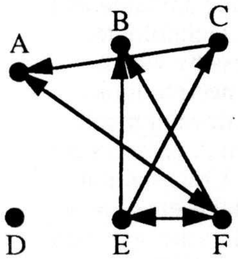


Figure 1
Sample Network

Network analysis is a set of methods based on mathematical graph theory used to describe the relations between people (e.g. "Who gives technical information to whom at least once per week?"), graphically expressed as directed lines connecting pairs of nodes (for example, Figure 1) and mathematically represented in matrices. The system can be analyzed at several levels: the individual, sub-group (or "clique"), and entire network. The technique has been used for well over two decades, during which time a body of underlying theory has developed, founded in the traditions of sociology, anthropology, and communications research[31,39]. It is currently becoming recognized as a useful tool for the study of specific aspects of organizational behavior, due to the availability of powerful computer programs for analysis. Networks are often defined using questionnaires with easy-to-answer questions about interactions between pairs of network members. Network scholars[11,15] assert that self-reports conform reasonably well to long-term behavioral patterns (or norms, in the absence of good recollection). Designing questions to capture long-term patterns and using multiple measures to assess reliability are two ways to address the issue of reported versus actual behavior in the design of data collection instruments and interpretation of network analysis results. Different topics, for example *knowledge of* and *decision to use* a new technology, can yield different network structures[29].

Granovetter theorized that the relative "strengths" of ties between people effect social processes. Tie strength is a combination of amount of time, emotional intensity, intimacy (mutual confiding), and reciprocal services; ties can be strong, weak, or absent[12]. He proposed that a network will contain dense groups of strongly-tied people (*cliques*) connected by weaker "bridging" ties. This implies that the diffusion of information takes place across weakly-tied cliques and that decision-making occurs within cliques[13].

Each network member has their own *personal network*, all of the people connected to a specific person. Individuals can be described by their location and role in the main network, as well as by the attributes of their personal network (for example, location in the overall network or degree of connectedness or number of actual links compared to the number of possible links). *Centrality* is a measure that reflects to what degree one network member is connected to all others and has been used as an indication of power in various studies[5,6].

One construction manager interviewed during an early phase of this research described networks as the "grapevine" for implementation of new technology. He acknowledged the prevalence of informal communication and the significant influence of organization (particularly the extent of centralization) on the diffusion of technology. He indicated that only senior operations managers need to make decisions about the use of new construction technology. With increased understanding of communication and roles for diffusion, this potentially limiting reality could become a driving force for quick adoption of new technology.

2.4 Network Analysis and Roles

A *role* is defined by characteristics of network position in conjunction with communication function. Table 1 summarizes key communication role functions and Figure 3 illustrates key communication roles by overlaying portions of a network onto a formal organizational structure. By combining individual and group levels of analysis, network techniques provide the means for identifying the members in the organization who are fulfilling key roles. A theoretical assumption of network analysis is that individual behavior is effected by the patterns of relationships surrounding each person[10]. Once these key individuals are located, the function of their roles can be assessed with respect to the diffusion process in the organization.

Table 1
Network Communication Roles

COMMUNICATION ROLE	FUNCTION IN THE NETWORK
Gatekeeper	Brings information into the network from the outside
Liaison	Interconnects parts of the network (cliques)
Opinion Leader	Influences informal decision making
Champion	Positively influences decisions and provides continuity over time.

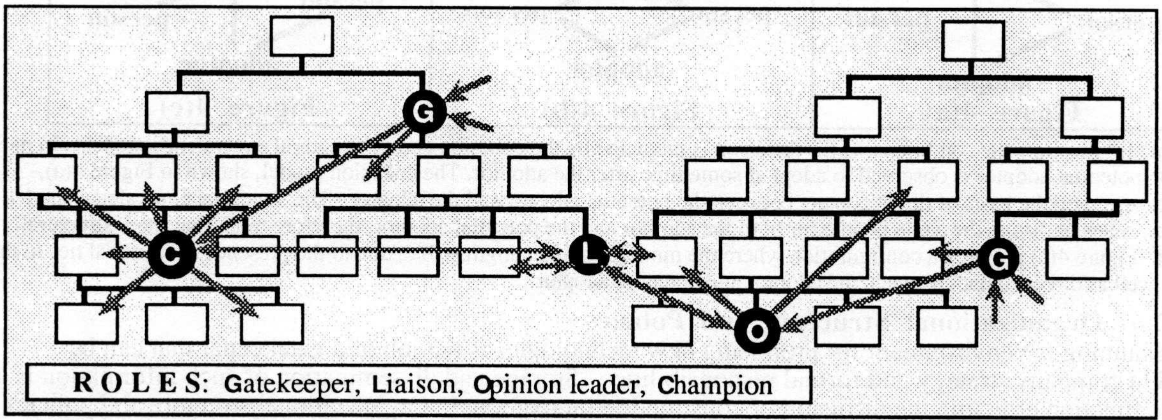


Figure 3
Informal Communication Roles and the Formal Organization

In network terms, a liaison is positioned between cliques and is an important role for diffusion of information. Technological gatekeepers, a type of liaison, are considered to be "critical link-pins between a working technical group and outside information sources"[1]. A *gatekeeper* has an unusually large number of contacts with external sources of information. These may be publications or people in other organizations. The gatekeeper collects and disseminates information to other members of the organization and can be identified by a high degree of centrality in a network that reflecting sources of technological information. They may also have a large number of connections to people who are not cited by other network members. In addition, liaisons can communicate between highly differentiated areas, in essence translating norms, values and language schemes[35] and become important "human bridges" in the internal technology transfer process[26].

Another important role is the *opinion leader*. Opinion leaders informally influence other individuals' attitudes or behavior and can be considered informal leaders[27]. They are typically prominant on the basis of technical proficiency, not formal position. In addition to their technical credibility, other people gravitate towards opinion leaders as a result of their "safety", that is, they are trusted to the extent that they represent the norms of the group[17]. Opinion leaders are expected to be highly central in technical advice networks. A champion can be recognized as an opinion leader who encourages adoption decisions for a particular innovation and is expected to have a large number of ties to different types of people. Due to the disparate backgrounds of researchers, developers, promoters, and users of construction technology, the integration champion fulfills a liaison role.

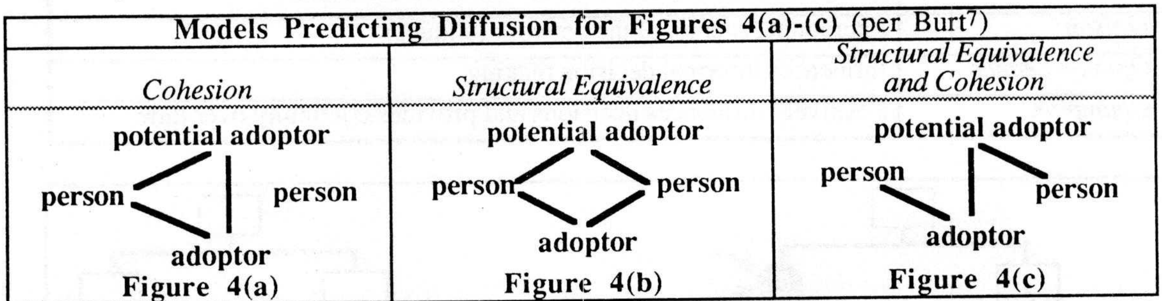
2.5 Network Diffusion Models

2.5.1 Cohesion

The *cohesion* model of diffusion assumes that a potential adoptor's attitude toward use or actual decision to use is mainly predicted by direct contact with users and opinion leaders. This model hinges on the social processes through which ambiguous questions are resolved by observation and discussion. Normative understanding of the relative risks and advantages of using an innovation are developed by conversations between people who rely on each other for advice in such matters, as well as by "vicarious trials" conducted by observing a new user[7,8,10].

2.5.2 Structural Equivalence

The *structural equivalence* model of diffusion was developed by Burt who "proposes that individuals are not simply acting out a generalized culture shared by everyone. Rather, they occupy particular kinds of positions in a social network. The actors' interests are shaped by their network position"[10]. Per Burt[7] "an actor will quickly adopt an innovation after actors he perceives to be structurally equivalent to him have adopted it." "Individuals who are central in their own cliques, or who have extensive ranges of contacts, are similar to each other and are different from persons who are peripheral in their cliques or have limited ranges of contacts"[10]. Two people in the same role are substitutable with respect to their relational ties[30], therefore competition is a primary force driving the beginning of the diffusion process, before adoption becomes normative for members of a particular role[7]. The cohesion and structural equivalence models are presented in Figures 4(a)-(c).



Figures 4(a)-(c) illustrate the conditions where diffusion is predicted by the cohesion and/or structural equivalence models. In these figures, the potential adoptor is observed to adopt at some time after the adoptor. The cohesion model, shown in Figure 4(a), explains diffusion on the basis of direct contact between the potential adoptor and the adoptor. The structural equivalence model, Figure 4(b), relies on ties to the same people for both the adoptor and the potential adoptor, therefore rendering them structurally equivalent. Figure 4(c) presents a configuration where the models are indistinguishable, due to the presence of identical ties to third parties, as well as direct contact between the adoptor and potential adoptor.

2.6 Organizational Structure and Policies

Scanning the environment for promising new technologies is the job of a gatekeeper that can be included in company strategy and formal responsibilities. Storage and dissemination of such information is a corporate function effecting the diffusion of construction innovations[4]. Organizational structure and policies regarding meetings and job rotations influence members' ability to discuss new technologies, therefore indirectly shaping the informal communication network. Construction site managers' attitude toward using and decision to use new technologies is a function of their risk evaluation. The following impact the evaluation of risk: the critera used for personnel evaluation ("freedom to fail" versus "bottom line"), technical support and training, the availability of slack resources[23], conformance to corporate technology strategy, the mode of decision making (group versus individual), the mechanism used to fund new technologies, job assignment rotations to inculcate understanding and support of new technologies, and adaptation of the technology by users to encourage their sense of ownership[3,17]. In addition, the ability of champions to perform is strongly effected by their formal power and authority[17,23].

What does all this background mean for construction? As with many topics related to technology, it indicates that we can learn from experience in manufacturing. The centralization of product design and process engineering in most manufacturing firms brings advantages related to acquiring and using new technology. Even with these advantages, historically slow rates of diffusion indicate opportunities to improve. The fragmentation of design and construction brings some new problems for technology development and diffusion. However, the organizational differences in many design and construction firms (some with notably less bureaucracy) may offer increased potential for more rapid adoption and use.

But first, the right people must find about new technology. Lack of incentives and knowledge may be restrainting more rapid use of automation technology in design and construction. The research described in the following sections is designed to get to the bottom of this. Can we automate faster? How?

(3) RESEARCH METHODOLOGY

3.1 Work to Date

Interviews conducted in a U.S. engineering/construction company allowed us to identify KRONOS, a micro-computer based automated timekeeping system using barcoded badges for employees. The data from these interviews were used to develop an initial questionnaire (see Appendix A), and locate another engineering/construction company as a potential participant. KRONOS is an ideal technology for this investigation because it is clearly economically advantageous (for construction sites with a large worker population requiring the use of several timekeeping employees for traditional methods), technically reliable, and is in the early diffusion phase (see Figure 5). Pending managerial approval, we will conduct a pilot study in one of these companies this summer (1992) to collect and analyze historical diffusion data.

3.2 Future Work

3.2.1 Technology Selection

Technologies to be studied will be selected to highlight the decision making authority of construction site managers. Technically efficient innovations offering substantial improvements in technical performance spread more rapidly than those that do not[20]. As much as possible, "technology winners" will be chosen to control for technical performance problems and to optimize the likelihood of documenting a sufficient portion of the diffusion process within the limited study duration. In the U.S., a prospective technology, KRONOS automated timekeeping systems, has already been identified and pilot study arrangements are underway. Two technologies in the early diffusion phase (see Figure 5) will be selected in each firm.

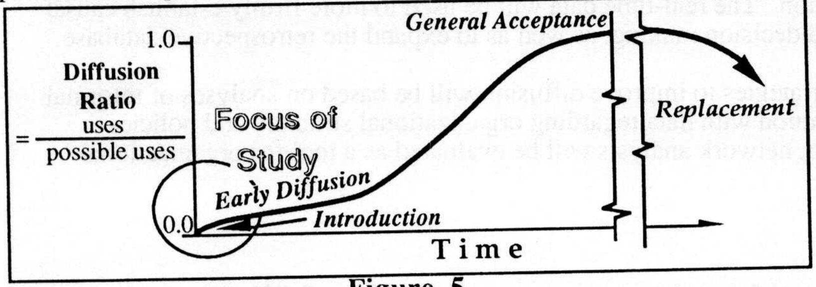


Figure 5
Diffusion Lifecycle

3.2.2 Population Definition

Interviews will be conducted to define the study population including all construction personnel responsible for the selection of the subject technologies, as well as personnel responsible for promoting and/or supporting the technology in the company. In addition, we will seek information about the dissemination of information and organizational policies and structure that may effect diffusion.

3.2.3 Data Collection and Analysis

After defining the population, the questionnaire will be "pre-tested" to ensure that respondents understand the intended meaning of the questions. Appendix A lists sample questions to be included on the questionnaire. Pre-testing involves distributing the questionnaire to a group of 5-7 people representing the population in an approximately hour-long meeting. A researcher will watch them fill out the questionnaire, then "de-brief" them to learn about any problems they had in understanding the questions. Based on the pre-test meeting, the questionnaire will be revised and distributed to all members of the study population. In order to effectively use network analysis, it is necessary to have everyone respond to the questions, therefore, we will include a cover letter from management, "blessing" the study, respondents will be assured that results will be kept anonymous, and follow-up cards and/or calls will be made, as needed.

Data will be collected by questionnaire to define a preliminary "snapshot" of the informal communication structure at the beginning of the study (t_0), as shown in Figure 6. This initial data will provide

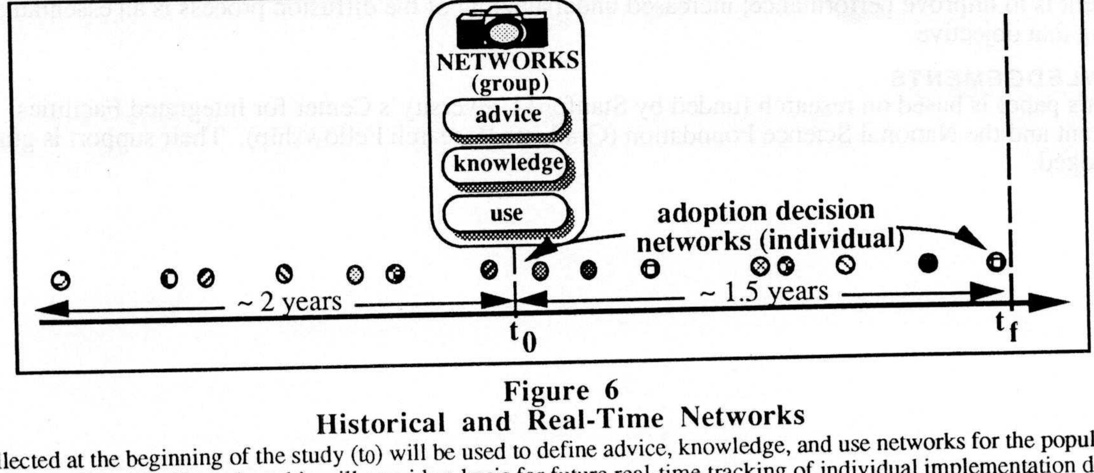


Figure 6
Historical and Real-Time Networks

Data collected at the beginning of the study (t_0) will be used to define advice, knowledge, and use networks for the population. In tandem with additional information, this will provide a basis for future real-time tracking of individual implementation decisions, as well as an analysis of historical diffusion processes.

a starting point for the real-time tracking of implementation decisions for the following 18 months, give information for a retrospective analysis of earlier diffusion phases, and direct further interviews.

Opinion leaders will be identified by the reputational technique[29], whereby supervisors will be asked to rank the opinion leader status of their subordinates and the resulting scores will be averaged. Roles will be identified by comparing the advice, knowledge and use network analyses, in conjunction with opinion leader and attitude data.

Network analysis will be performed using UCINET, a PC-based computer program and graphics will be created using NetMap on a workstation. Multiple regression analysis of the matrix data representing network relationships will be used to assess the relative importance and significance of the cohesion and structural equivalence diffusion models, plus personal characteristics, for predicting knowledge and use. A more detailed explanation of this technique, based on Burt[7], is presented in Appendix B.

During the real-time study period (t_0 to t_f in Figure 6), personal network data will be collected for each person involved in an implementation decision. The real-time data will be used to more firmly establish causal relationships between network structure and decision making, as well as to expand the retrospective database for a longer time period.

Recommendations for managerial strategies to improve diffusion will be based on analyses of informal communication patterns and roles in conjunction with data regarding organizational structure and policies impacting the diffusion process. In addition, network analysis will be evaluated as a tool for organizational diagnosis and improvement.

(4) RESULTS AND SIGNIFICANCE

4.1 Expected Results

The core of this research is assessment of the relative importance of the mode of diffusion (cohesion versus structural equivalence) and personal characteristics in explaining observed diffusion of knowledge and use.of construction site technology. Important roles will be identified by analysis of the advice, knowledge and use networks and this data will be augmented by information from interviews. Demographic information (age, education, and career variables, per Appendix A) will be used to evaluate the impact of differences in backgrounds and norms by comparison with both clique membership and structural equivalence groups. The impact of organizational structure and policies will be investigated by comparing network and formal structures, and additional questionnaire items, in addition to interview data . The knowledge gained from this study will be used to develop recommendations for managerial strategies to improve diffusion of construction technologies.

4.1 Contributions

The network analysis results from this research will augment the innovation role literature in manufacturing and construction. Testing the relative importance of cohesion, structural equivalence, and personal characteristics in the explanation of diffusion will add to the construction innovation literature, as well as providing the case of construction to the diffusion literature. In addition, the study will evaluate network analysis as a tool for organizational diagnosis and provide recommendations for managerial strategies to improve diffusion based on analysis of informal communication patterns and roles in conjunction with organizational structure and policies.

Although it is recognized that the use of new technology can be important for improving competitiveness, we do not mean to imply that diffusion is the sole ingredient for success. The ultimate goal of management is to improve performance; increased understanding of the diffusion process is an essential aspect of attaining that objective.

ACKNOWLEDGEMENTS

This paper is based on research funded by Stanford University's Center for Integrated Facilities Management and the National Science Foundation (Graduate Research Fellowship). Their support is gratefully acknowledged.

(5) BIBLIOGRAPHY

1. Allen, T.J. (1977), *Managing the Flow of Technology*, Cambridge: MIT Press in Edward B. Roberts (ed.), *Generating Technological Innovation*, New York: Oxford University Press, 1987, pg. 12.

2. Aoki, Masahiko and Nathan Rosenberg (1987), *The Japanese Firm as an Innovating Institution*, CEPR Publication No. 106, Center for Economic Policy Research, Stanford University.

3. Bikson, T.K., B. A. Gutek and D.A. Mankin (1981), *Implementation of Information Technology in Office Settings: Review of Relevant Literature*. Santa Monica, CA: Rand Corporation. Publication No. P-6697 in Louis G. Tornatzky, et al. (1983), *The Process of Technological Innovation: Reviewing the Literature*, Productivity Improvement Research Section, Division of Industrial Science and Technological Innovation, Washington, D.C.: National Science Foundation, pg. 147.

4. Björklöf, Sune (1986), "The Building Sector's Propensity for Innovation," *Linköping Studies in Management and Economics, Dissertations, No. 15*, Department of Management and Economics, Linköping University, Linköping, Sweden.

5. Bonacich, P. (1987), "Power and centrality: A family of measures", *American Journal of Sociology*, 92, pp. 1170-82.

6. Burkhardt, Marlene E. and Daniel J. Brass (1990), "Changing Patterns or Patterns of Change: The Effects of a Change in Technology on Social Network Structure and Power", *Administrative Science Quarterly*, 35(1), pp. 104-127.

7. Burt, Ronald S. (1982), *Toward a Structural Theory of Action: Network Models of Social Structure, Perception, and Action*, New York: Academic Press.

8. Burt, Ronald S. (1987), "Social Contagion and Innovation: Cohesion versus Structural Equivalence," *American Journal of Sociology*, 92(May 1987), pp. 1287-1335.

9. Business Roundtable (1982), *Technological Progress in the Construction Industry*. A Report of The Construction Industry Cost Effectiveness Project. Report B-2, New York: Business Roundtable, July, 1982.

10. Collins, Randall (1988), *Theoretical Sociology*, New York: Harcourt Brace Jovanovich.

11. Freeman, Lin, Kim Romney and Sue Freeman (1987), "Cognitive Structure and Informant Accuracy," *American Anthropologist*, 89, pp. 310-325.

12. Granovetter, M. S. (1973), "The strength of weak ties," *American Journal of Sociology*, 78, pp. 1360-1380.

13. Granovetter, M. S. (1983), "The strength of weak ties: A network theory revisited," in Collins, Randall (ed.), *Sociological Theory*, San Francisco: Jossey-Bass, pp. 105-130.

14. Gregory, Kathleen L. (1983), "Native-View Paradigms: Multiple Cultures and Culture Conflicts in Organizations," *Administrative Science Quarterly*, 28, pp. 359-376.

15. Krackhardt, D. (1987), "Cognitive social structures," *Social Networks*, 9, pp. 109-134.

16. Krackhardt, D. (1988), "Predicting with networks: Nonparametric multiple regression analysis of dyadic data", *Social Networks*, 10, pp. 359-381.

17. Leonard-Barton, Dorothy and William A. Kraus (1985), "Implementing New Technology", *Harvard Business Review*, Nov-Dec, pp. 102.

18. March, James G. (1988a), "The Technology of Foolishness," in James G. March (ed.), *Decisions and Organizations*, Cambridge: Basil Blackwell, pp. 253-265. First published in *Civiløkonomen*, Copenhagen, 18, 1971.

19. March, James G. (1988b), "Bounded Rationality, Ambiguity, and the Engineering of Choice," in James G. March (ed.), *Decisions and Organizations*, Cambridge: Basil Blackwell, pp. 266-293. First published in *The Bell Journal of Economics*, Vol. 9, No. 2, Autumn, 1978.

20. March, James G. and Lee S. Sproull (1990), "Technology, Management, and Competitive Advantage," in Goodman, Paul S. and Lee S. Sproull and Associates (ed.), *Technology and Organizations*, San Francisco: Jossey-Bass, pp. 144-173.

21. Marquis, Donald G. (1988), "The Anatomy of Successful Innovations," in Michael Tushman and William Moore (ed.), *Readings in the Management of Innovation*, Ballinger Publishing Co. Originally in *Innovation*, November, 1969 and *Managing Advancing Technology*, Volume I, 1972, pp. 35-48.

22. Minemasa, Katsuyoshi (1990), "Experience in Managin R&D and Implementation of Advanced Technologies," *Center for Integrated Facilitiy Engineering Technical Report No. 24*, Stanford University, March 1990.

23. Nam, C. H., J. G. Gasiorowski, and C. B. Tatum. (1991), "Microlevel Study of Integration in High-Strength Concrete Innovation," *Journal of Construction Engineering and Management*, A.S.C.E., Vol. 117, No. 21991, pp. 294-309.

24. National Research Council. Commission on Engineering and Technical Systems. Building Research Board. Committee on Construction Productivity (1986), *Construction Productivity: Proposed Actions by the Federal Government to Promote Increased Efficiency in Construction*, Washington, D.C.: National Academy Press.

25. Ord, K. (1975) "Estimation methods for models of spatial interaction," *Journal of the American Statistical Association*, 70 (March), pp. 120-126.

26. Roberts, Edward B. (1987) ed., *Generating Technological Innovation*, New York: Oxford University Press.

27. Rogers, Everett M. and Rekha Agarwala-Rogers (1976), *Communication in Organizations*, New York: The Free Press.

28. Rogers, Everett M. and D. Lawrence Kincaid (1981), *Communication Networks: Toward a New Paradigm for Research*, New York: The Free Press.

29. Rogers, Everett M. and F. Floyd Shoemaker (1971), *Communication of Innovations: A Cross-Cultural Approach*, New York: The Free Press.

30. Sailer, Lee Douglas (1978), "Structural Equivalence: Meaning and Definition, Computation and Application," *Social Networks*, 1, pp. 73-90.

31. Scott, John (1991), *Social Network Analysis*, Newbury Park, CA: Sage Publications.

32. Seaden, George (1992), "The International Transfer of Building Technology," *Construction Business Review*, (January/February), pp. 50-55.

33. Tatum, C. B. (1989), "Organizing to Increase Innovation in the Construction Firm," *Journal of Construction Engineering and Management*, A.S.C.E., 115(4), pp. 602-617.

34. Tornatzky, Louis G., et al. (1983), *The Process of Technological Innovation: Reviewing the Literature*, Productivity Improvement Research Section, Division of Industrial Science and Technological Innovation, Washington, D.C.: National Science Foundation.

35. Tushman, Michael (1988), "Managing Communication Network in R&D Laboratories," in Michael Tushman and William Moore (ed.), *Readings in the Management of Innovation*, Ballinger Publishing Co. Originally in *Sloan Management Review*, Winter 1979, pp.37-49.

36. U.S. Congress Energy and Materials and Science, Education, and Transportation Programs Office of Technology Assessment (1987), *Construction and Materials Research and Development for the Nation's Public Works*.

37. U.S. House of Representatives (1989), *R&D in the Construction Industry*, Hearing before the Subcommittee on Science, Research and Technology of the Committee on Science, Space, and Technology [No. 55], Washington, D.C.: U.S. Government Printing Office. ($54M vs. $800M)

38. von Hippel, Eric (1988), *The Sources of Innovations*, New York: Oxford University Press.

39. Wellman, Barry and Stephen Berkowitz (1988), *Social Structures: a network approach*, New York: Cambrige University Press.

APPENDIX A: SAMPLE QUESTIONS

Questions marked with an asterisk (*) will refer to a list of all people in the study population. These questions were prepared for a pilot study of the Kronos automated timekeeping system. The same questions will be asked for the other technologies under investigation.

- Typical sources of technological advice
  **When you need to discuss automation technologies:*
  Who do you talk to (check off names on list, plus fill-in for those not on list and if in company: add department, outside company: add company name)?
  How many times per year, per month, per week (fill in number)?
  How important are your discussions (scale of 1 to 4)?
  How long have you known them (years)?
- Knowledge of KRONOS automated timekeeping system (or any other specific technology)
  Have you ever heard about KRONOS automated timekeeping system (y/n)
  If you have, please fill in the following information (purpose, alternatives, approx. capital and operating costs and savings)
  Where did you find out about KRONOS (list sources of information, e.g. company newsletter, company meeting, talking to someone, etc.)?
  **Who have you spoken with about Kronos (check off names on list, plus fill-in for those not on list and if in company: add department, outside company: add company name)?*
  **If you first found out about Kronos from talking to someone, who did you talk to (check off names on list, plus fill-in for those not on list and if in company: add department, outside company: add company name)?*
  **If you have told anyone else about Kronos (who hadn't heard about it before), who did you tell (check off names on list, plus fill-in for those not on list and if in company: add department, outside company: add company name)?*
- Attitude toward KRONOS (or any other specific technology)
  Would you use KRONOS on a project (scale of 1 to 5)?
  Would you advise someone else to use KRONOS on a project (y/n)?
  What does your supervisor think about using KRONOS on one of your projects (scale of 1 to 5)?
- KRONOS use decision (or any other specific technology)
  Have you considered using KRONOS on a project (y/n)?
  If you have, when did you make your decision (month, year)?
  What type of contract was it (fixed, cost reimbursable, unit rate; direct hire, construction management, etc.)?
  Did you decide to use KRONOS (y/n)?
  Why did you decide to use KRONOS (it was a better method, I was told to use it {by whom?}, the client requested use, other)?
  If you decided not to use KRONOS, why (site problems, labor problems, not included in contract, preferred to use the traditional method, etc.)
  **Who did you talk to regarding your decision (check off names on list, plus fill-in for those not on list and if in company: add department, outside company: add company name)?*
  About how often did you talk with them (fill-in number)?
  How important was your talk(s) with them (scale of 1 to 4)?
  About how long have you known them (years)?
  If you used KRONOS on a project, did it perform as you expected (y/n)?
  If it did not perform as expected, why (list of potential reasons, like hardware problems, software problems, insufficient training support, insufficient technical support, physical layout of site, subcontractor objections, cost, etc.)?
- *Personal information*
  age (ranges)
  education (scale with durations, e.g. high school, 2-year college, etc.; list of disciplines)
  career (number of years in construction; list of positions held; number of companies)
  sources of technical info.(newsletter, meeting(s), new technology dept, magazines/ journals per month)

APPENDIX B: TESTING ALTERNATIVE DIFFUSION MODELS

The following is the derivation of an equation used by Burt[8] to test the mechanism(s) driving individual adoption decisions, thereby allowing comparison of the relative importance of cohesion, structural equivalence and personal characteristics in the diffusion of an innovation through a population.

$j \equiv$ potential adoptor

$t_j \equiv$ potential adoptor's resources

$u_j \equiv$ potential adoptor's subjective perception of his resources

and $u_j = \mu t_j^{\nu}$ where μ and ν are constants for the population

The potential adoptor's evaluation of adoption advantages are a function of the rate at which subjective perception increases with actual resource increase:

$$\frac{du_j}{dt_j} = \nu\mu t_j^{(\nu-1)} = \nu\frac{u_j}{t_j} \quad (1)$$

Equation 1 is expanded to include the potential adoptor's social frame of reference:

$$\frac{du_j}{dt_j} = b_p\left(\frac{\nu u_j}{t_j}\right) + b_s\Sigma_i\frac{w_{ji}u_j}{t_i} \quad \text{for } 0 \leq w_{ji} \leq 1 \text{ and } w_{jj} = 0 \quad (2)$$

Where w_{ji} is a fraction expressing the extent to which person i defines the social frame of reference for the potential adoptor's evaluation, therefore w_{ji} could reflect cohesion or structural equivalence.

and: $\Sigma_i\frac{w_{ji}u_j}{t_i} \equiv$ potential adoptor's social evaluation of his adoption compared to all others in his reference group

$b_p \equiv$ coefficient for weighting personal factors

$b_s \equiv$ coefficient for weighting social factors

The above, simplified for operationalization:

$x_j \equiv$ potential adoptor's adoption decision $= b_pP_j + b_s\Sigma_i w_{ji}x_i + e_j = b_pP_j + b_sx_j^* + e_j$ (3)

and $P_j \equiv$ index reflecting personal characteristics

$e_j \equiv$ residual term

$x_j^* \equiv$ the potential adoptor's adoption norm, e.g. the date on which the potential adoptor's reference group members adopted (for either cohesion or structural equivalence)

$$w_{ji} \equiv \frac{(\text{proximity j to i})^{\nu}}{\Sigma_k(\text{proximity j to k})^{\nu}}, \ k \neq j \quad (4)$$

for the potential adoptor's subjective perception of his proximity in the social structure to some adoptor, i.

In equation 4, the extent to which the potential adoptor relies on others is reflected by the magnitude of the exponent ν. Values of ν greater than 1 indicate that only the closest members of the potential adoptor's reference group are pertinent, while small values of ν signify a much wider social frame of reference for his evaluation of the innovation. For a given population, the appropriate value of ν can be found by comparing predicted and observed adoption for a range of ν's and selecting the value that yields the best predictions.

Equation 3 can be expressed in matrix form: $\mathbf{X} = b_p\mathbf{P} + b_s\mathbf{WX} + \mathbf{E}$ (5)
where **X** is a vector of adoption dates, **P** is a vector of personal preference data, **E** is a vector of residuals, and **W** is a matrix of network weights (defined in equation 4). The product **WX** defines a vector of adoption-date norms ($\mathbf{X}^*$), b_p measures the effect of personal preference on adoption, and b_s is a coefficient measuring the effect of other adoptor's on the potential adoptor's decision. Due to the non-independence of observations used for $\mathbf{X}^*$, the calculation of b_s and its significance cannot be performed using ordinary least squares analysis, however, according to Krackhardt[16], there are approaches to be used in this case[25].