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A Grassroots Model of Decision Support System Implementations by Construction Project Teams

By

Timo Hartmann

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If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
The Jerry Yang & Akiko Yamazaki Environment & Energy Building
473 Via Ortega, Room 292, Mail Code: 4020
Stanford, CA 94305-4020

A GRASSROOTS MODEL OF DECISION SUPPORT SYSTEM IMPLEMENTATIONS BY CONSTRUCTION PROJECT TEAMS

A DISSERTATION
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Timo Hartmann
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Certifications

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Professor Martin Fischer, Principal Adviser

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Professor Raymond E. Levitt

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Professor John R. Haymaker

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Professor Geert P. M. R. Dewulf

Approved for the University Committee on Graduate Studies.

Abstract

This thesis explains grassroots implementations of decision support systems by project teams - implementations driven by the members of a project team working at the operational level - from the perspectives of the three main stakeholders that are involved in managing the life-cycle of a decision support system: project team members, technology managers of project-based companies, and developers of decision support systems.

Using ethnographic data from a large infrastructure construction project in New York City the thesis shows that the project team on this project was only able to use a decision support system efficiently when the members of the project team were driving the decision support system implementation in a grassroots process. The project team members mutually structurated the technology and their knowledge throughout the grassroots implementation. They influenced the technical reality of the decision support system while at the same time being influenced by the technical reality of the system.

Existing micro-sociological theories do not sufficiently describe such grassroots processes because they do not consider special characteristics of project teams and decision support systems that influence the implementation. In particular, these models usually assume four points that do not match the specific characteristics of the implementation of decision support systems by a project team: they assume that upper management can mandate the use of the technology; they assume that organizational members are able to successfully implement the technology individually without a wide acceptance and level of integration within the organization; they assume that organizational members are granted the time to learn the technology slowly; or they assume that a fixed political structure exists that influences the implementation.

Building on the findings of the case study, the thesis, therefore, deductively integrates existing work that can explain parts of grassroots processes into a coherent theoretical model. The model explains how members working at the operational level of a project team make sense about a newly introduced decision support system and decide to utilize it in their local context. In this way, the thesis applies social sense making theory to decision support systems implementations and positions the grassroots technology implementation model into organizational choice theory, organizational multi-level theory, and organizational change theory.

Based on the theoretical model the thesis recommends that technology managers need to work closely together with local project teams during the implementation of decision support systems to support grassroots processes, instead of trying to push down standardized technology solutions through hierarchical structures. Additionally, the thesis proposes a project-centric research and software development methodology to inform the design of decision support systems that project teams need to implement in a grassroots fashion. The thesis suggests that technology developers use ethnographic action research to develop decision support systems that can easily be appropriated by project teams to changing project cultures. To provide validity and generality for the usefulness of the technology development methodology the thesis uses data from another set of four in-depth case studies that iteratively implemented technologies to support the decision making of project team members.

Acknowledgements

For me the most important part during completing the enormous task of a Ph.D. thesis is intuition. Intuition is important for every research step along the way, from deriving initial problems from field observations and selecting the research method that is best suited to describe and solve the problem, to while presenting the findings orally and in written form. While other research tasks can be accomplished individually by hard work, intuition comes seldom and often unforeseen, but most often during conversations with others. Therefore, I would like to thank a number of people that helped me during my search for intuition during the four years I worked on this Ph.D. thesis.

The first group of people I would like to acknowledge is my committee members. I am gratefully to my advisor Martin Fischer, who allowed me to explore a new area of research that deviates from the technology centric research of his group. Martin helped me throughout my endeavor, offered me the possibility to discuss my research with members of his vast professional network, and, probably most importantly, shaped my technical writing. Thanks to Martin I started to enjoy writing so much that I decided to stay in academia. Second, I would like to thank Ray Levitt in providing me with a role model as a researcher that I will happily try to follow throughout the rest of my career. I consider him as one of the sharpest persons I know, and even though he is one of the most critical, Ray is also one of the most open minded persons I know. At times it was not easy to satisfy his stringent academic requirements, but in the end I have to thank Ray, because this thesis would not be what it is without his help. Third, there is John Haymaker, who provided me with guidance and help and with a good example of how to balance life and complete a Ph.D. John and I shared an office at CIFE back when he was still working on his Ph.D. and he became a good friend over time. The fourth committee member is Geert Dewulf, who provided me with the necessary help in positioning this thesis within the broad sociology literature and a number of possibilities to present and discuss my work at his fantastic department at Twente University. Discussions in the Netherlands and on the beach in the Bahamas helped me to sharpen the constructs presented in this thesis and I sincerely regret that I did not meet Geert earlier. And finally, there is Kristian Kreiner, who gave me the feeling to be not alone in the construction world with my understanding that the complexity of the construction industry is necessary to shape the unique and beautiful build environment. Kristian taught my engineering mind to celebrate the complexity prevailing in our industry and to focus my research on supporting engineers to work in complex environments instead of rationalizing the complexity of their work tasks away.

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1 Introduction

We are filled with awe and amazement when visiting sights of human achievement, such as the great pyramids of Giza, the Pantheon in Rome, or the Golden Gate Bridge in San Francisco. Often visitors at these places transfer themselves in their minds from the present sight to the construction site. They imagine how it was possible to build these wonders of the world without the latest achievements in technology. Engineers often start to reflect about the technical requirements that were necessary to build these monuments. Some of the questions they try to understand might be (all data from Wikipedia.com):

- "How was it possible to coordinate a peak of 40,000 workers and the timely delivery of 2.4 million stone blocks to build the great pyramid of Giza without critical path scheduling?"
- "How was it possible to span the 142 ft. diameter Pantheon that carries about 5,000 tons without finite element analysis software?"
- "How was it possible to communicate the complicated and at that time novel design requirements for the Golden Gate Bridge without the use of 2D and 3D CAD?"

Turning these questions around, engineers might easily come to the conclusion that, while building these wonders of the world was a great achievement back in the days, today with the latest development in technologies building such monuments should not pose much of a problem any longer.

However, the reality is different. Projects (all data from Wikipedia.com), such as the Central Artery in Boston significantly overrun budgets and schedules despite the use of critical path scheduling methodologies. Structures collapse, like the I-35W Mississippi Bridge in Minnesota that killed 13 people, or the 2E Terminal at Charles de Gaulle airport that killed 4 people, despite the use of sophisticated finite element programs during their design. Finally, projects still suffer under a large number of change orders due to miscommunication of designs despite the use of 2D and 3D CAD technologies. Looking closer at the productivity and safety data of the construction industry these failed projects seem to be just the tip of the iceberg (Teicholz 2004).

In this thesis I try to shed some light on the question of why AEC professionals could not leverage the promised potential of such decision support systems. I will provide insights into some of the rudimentary problems with implementing decision support systems on construction projects. In addition to the practical experiences I gained working as a project manager and with a software company that develops finite element software, the findings of this thesis are largely influenced by a two year case study on a large construction project in

Manhattan, New York City. On the project in New York I learned three important characteristics of AEC projects. The first is that construction operates in complex environments (Kreiner 1995); the project involved the reconstruction of seven major subway lines in Downtown Manhattan while maintaining all the subways operational for more than 200,000 passengers daily. The second characteristic is that project teams are detached from the formal authority of their companies (Cohen & Bailey 1997); the project team on the case was a joint venture between two construction management companies that was specifically established for this project. Finally, I learned that on construction projects each member of the project team usually works on a relatively autonomous tasks. At the same time, however, each member also needs to consistently consider informational input from other members of the project team. Therefore, tasks in project environments are highly reciprocally interdependent (Gann & Salter 2000; Thompson 1967).

The project in New York was well suited to inform this thesis. The project team decided to use a decision support system to support decisions during the planning of the necessary construction work. This system, a 4D CAD (3D geometry plus time) application, was designed to visually simulate the planned construction sequence. These simulations start with the existing conditions at the construction site and end with the proposed final state of the project. Current 4D systems consist of a loosely integrated bundle of hardware, such as projectors, servers, or laptops, and software, such as 3D modeling applications, scheduling programs, and 4D viewers. Therefore, the project team needed to appropriate the hardware and software bundles by developing working processes to use the system efficiently. Only when the project team was able to configure the system appropriately was it able to support the decision making necessary to plan the complex and unique construction work. Some of these developed processes, additionally, required the project team to adjust their existing work processes and social structures. Additionally, the project team was detached from the formal hierarchy of the company. Thus, the influence of upper management agencies on the configuration of the system and the adaptation of the social project team structures was limited. Thus, I observed the phenomenon that the project team members themselves had to drive the implementation of the system from the grassroots of the project.

1.1 Research Questions and Theoretical Points of Departure

To explain these observations of the project theoretically this thesis provides answers for the following research question:

1. How can we describe the grassroots process that occurs during the implementation of decision support systems by project teams?

and specifically,

a) How do project teams make sense about a new decision support system?
b) How do project team members use the decision support system according to the outcomes of the sense-making process?
c) How does the interaction of individual project team members with the technology influence the sense-making process of the team?

A number of theories provide some answers for some parts of the first research question. However, these theories can only describe parts of my observations on the project. For example, Davis (1989) describes how perceptions about a decision support system influence individual decisions to use the system. However, the decision processes of whether to use the system or not on the project were jointly influenced by the members of the project team. Thus models that describe how individuals utilize decision support systems do not explain the findings on the project well. To consider the social processes during the implementation, social construction of reality (Berger & Luckmann 90) explains how organizations mutually make sense about their environment. Furthermore, structuration theory (Giddens 1986) explains how organizations socially construct their environment and are influenced by the environment at the same time. Both of these social theories have been used to describe how organizations appropriate the social system (Barley 1986; Orlikowski 1992) during technology implementations. Additionally, theorists have described how organizations configure technologies (Rice & Rogers 1980; Leonard-Barton 1988) to their social processes. However, both of these theories individually cannot show how project team members make sense of a decision support system. Furthermore, they cannot show how project teams adjust the decision support system to their local social system and their social system to the decision support system at the same time. The main reason for the shortcomings of these existing theories is that they do not consider the characteristics of projects and decision support systems in detail. For example, the existing research does not consider configuration processes (Rice & Rogers 1980; Leonard-Barton 1988) of decision support systems that consist of a loose bundle of features (Bidgoli 1997). Furthermore, the existing technology structuration research does not focus on implementations in complex project environments (Kreiner 1995) in which project teams work detached from the formal authority of the company (Cohen & Bailey 1997).

To answer the above research questions, this thesis, therefore, builds upon these existing research areas and develops a theoretical model that explains grassroots processes specifically for the implementation of decision support systems by project teams. We expect that the model will be useful for both project managers and technology managers of project-based companies to understand the implementation process of decision support systems better.

Additionally, on the projects I have been involved with during my Ph.D. studies I realized another problem. Commercially available decision support systems for the use within complex project environments usually do not support the necessary appropriation of the technology well that needs to occur during the grassroots implementation. Therefore, this thesis also provides answers to the following question:

2. How can we develop decision support systems that project team members can appropriate easily together with technology developers to the sense-making outcomes of project teams?

To answer research question two this thesis proposes a new theoretical methodology of how to develop decision support systems within AEC project contexts. The methodology combines ethnographic research methods (Spradley 1979; Heritage 1984) and action research methods (Eden & Huxham 1996; Baskerville & Wood-Harper 1996).

1.2 Research Method

This thesis tries to bridge social science research that mainly focuses on describing and explaining social activity (Giddens 1990), and engineering-management research that focuses on providing solutions for discovered practical problems. To do so, this thesis uses three different research methodologies to address the three intended audiences of project managers, technology managers, and technology developers. First, the thesis uses a participatory field study that is explanatory and exploratory in nature (Jorgensen 1989). This field research enabled me to address project managers who intend to implement decision support systems on their projects because they can relate to the details of the participatory field study. The thesis, then, extends the constructs that emerged from the fieldwork into a theoretical model. This theoretical model extends the initial constructs from the field study into a complete and coherent model (Hannan et al. 2007). Due to the theoretical nature of this part of the thesis, technology managers of project based companies can learn how to structure implementation efforts on their projects better. Finally, the thesis develops a technology implementation and development methodology. The thesis uses case study research to provide evidence for the usefulness of this methodology (Yin 2003; Eisenhardt 1989). This part of the thesis especially helps technology managers, but also technology developers and researchers, to support the development and implementation of decision support systems for projects.

To elaborate, the thesis starts by describing my experiences as a one year participant-observer on the above mentioned construction project. During this fieldwork I tried to integrate myself as a member of the project team as much as possible. This close integration allowed me direct access to what the project managers thought, did, and felt. Thus, participant observation allowed me to describe my observations from the perspective of the project managers on the project accurately, objectively, and truthfully (Jorgenson 1989:56). After my fieldwork efforts, I started to develop theoretical constructs hewing as close to my observations as possible. During this effort, I consulted extant literature that informed some of my emergent constructs. In this way, I developed a number of grounded explanations that explained my experiences. These grounded explanations also furthered my understanding that the decision support system on the project was implemented in a grassroots process without much help from agencies outside the project team.

After the inductive development of the grounded explanations I realized that my data could only cover some aspects of grassroots implementation processes. The explanations were neither complete nor coherent. Therefore, I started to extend the initial grounded explanations by deductively integrating formal theories from organizational science, sociology, and management information systems. With these theories I developed a coherent theoretical model of the grassroots implementation of decision support systems by project teams.

Finally, the development of the model and the model itself, in turn, allowed me to understand decision support system implementations better. Using this better understanding, I developed a theoretical method to develop and implement decision support systems on projects to improve the management of grassroots implementations. I applied the development and implementation method on four other projects to provide empirical evidence that the method can help support grassroots implementations in practical contexts.

1.3 Contributions

This thesis develops a model of grassroots decision support system implementations by project teams. As described in the previous section, the thesis does so, by developing a number of grounded explanations from observations on one construction project. The thesis then integrates extant theories from the fields of sociology, organizational science, management information systems, and management science that extend these grounded explanations to a model that is internally coherent. In this way, the thesis develops a mechanism that can explain the implementation of decision support systems by project teams. Additionally, the thesis derives an ethnographic action research methodology that is well suited to develop decision support systems that project teams need to implement in a grassroots fashion.

The grassroots decision support system implementation model by project teams explains the process by which a project team mutually generates the spirit of a decision support system. This spirit describes the subjective characteristics of the system as they are jointly perceived by the members of the project team. The model proposes that, during the process of establishing the spirit, experienced project team members shape the spirit more than inexperienced members. The model, furthermore, assumes that actors external to the project team, such as technology managers of the project team's company, consultants, or R&D professionals have no coercive power to influence the implementation. These external actors lack power because project teams are detached from the formal hierarchical power structure of the project-based company. Therefore, the role of these outside agencies is that of fashion setters who influence the implementation effort only by shaping the spirit of the decision support system using rhetorical means.

The model furthermore explains that the gap between the objective reality of the system in use and the subjective spirit that is established influences the sense-making of project team members. In particular, the model explains that the gap influences how project team members perceive the control they have over the implementation of the system and how they perceive the opportunity that the system offers them to improve decision making tasks. The model proposes that project team members who, during the sense-making process, gain a feeling of control over the implementation of the system and who perceive that the system offers opportunities to improve their decision making tasks maximize the possible benefits the technology offers. In contrast, project team members who conclude that they do not have control over the implementation of the technology and who do not think that the system is an opportunity are likely to try to minimize expected negative consequences of the technology implementation. These project team members are not likely to utilize the new technology and are likely to avoid using the decision support system as much as possible. Finally, the model proposes that the individual knowledge of the project team members is influenced when project team members utilize the decision support system.

With the above propositions the grassroots model explains how the implementation of a technology is driven by team members working at the operational level of an organization. In this way, the grassroots model opens a fresh perspective for technology implementation theories that traditionally focus on top-down implementation models. The grassroots model does so by considering a number of project-specific and decision support system specific factors of the implementation process. First, the grassroots model considers the influence of the level of integration of the decision support system in the project team. Second, the grassroots model asserts that the use of the decision support system cannot be mandated by higher level agencies. Third, the grassroots model considers the temporal character of projects on the implementation. Fourth, the grassroots model considers that the features of decision support systems can be arranged in many different ways. Finally, the grassroots model considers the flat formal hierarchy of the project team.

In addition to the development of the grassroots model, the thesis shows that there exists a large gap between the potential benefits of existing commercial decision support systems for AEC projects and their technical ability to support AEC project routines. The thesis suggests ethnographic action research as a new project-centric way to develop decision support systems that project teams can easily adapt to their local project conditions. This adaptability of such systems to local project contexts then, in turn, reduces the gap between potential benefits and technical functionalities. The methodology combines the ethnographic observations of practitioners working in local project cultures and the iterative improvement of decision support systems directly on these projects in small ethnographic action research implementation cycles. By specifically focusing on the development of decision support systems for project environments this new methodology offers a first step to improve software development in project-based industries.

Summarizing the contributions, with the grassroots model of decision support implementation by project teams and the ethnographic action research methodology this thesis contributes to existing knowledge in the areas of organizational theory, project management, and management information systems theory in a several different ways. The thesis complements existing organizational theory by applying social sense-making theories and the sociology of socialization to the technology implementation process. Furthermore, with the grassroots model of decision support system implementations by project teams, this application of social sense-making models also moves the field of project management forward by providing an implementation theory that considers the specific characteristics of project teams as an organizational form. In the same light, the model gives new insights into management information science by considering the specific characteristics of decision support system technologies during implementation processes. The thesis additionally advances the field of management information science by developing the ethnographic action research methodology that provides a method that technology developers can use to develop decision support systems within the complex environments on projects.

1.4 Flow and Format of the Dissertation

This dissertation uses the "three paper format" presenting the findings of the research within stand-alone chapters that represent documents that are targeted for peer-reviewed academic journals. I chose this format for a number of reasons. First, I hope that the "paper format" enables the members of the three different groups of stakeholders that my research addresses, the project manager, the technology manager, and the technology developer, to easily identify the sections that are of most interest to them. Second, the structure of the thesis reflects how I developed the theoretical constructs I present: Chapter two presents the detailed participatory case study in depth; chapter three complements the findings of this case study by drawing on selected theories from the management information science and organizational science literature to build an integrated theory of technology adoption in project teams; and finally, chapter four derives a technology development method for system developers that is based on the theoretical model developed earlier. As a third reason for the paper format, I hope that the format will facilitate my efforts to publish the findings of my Ph.D. research. Finally, by dividing the whole Ph.D. thesis into stand-alone pieces I anticipate that my committee will be able to review and comment on my research findings more easily.

As I plan to publish each of the chapters together with co-authors, I used plural pronouns, such as "we" and "our" throughout chapters. Organizing the findings of my research it was not always possible to identify clear-cut boundaries between the different chapters, while at the same time ensuring that all chapters can be read without the context of the others. I tried to minimize repetitions of material whenever possible, but some redundancies were unavoidable.

The chapters of this thesis are organized as follows:

In chapter 2, I represent the perspective of the construction manager. The chapter explains the implementation of a 4D system to support the constructability review by a project team working on the construction project in New York City. The paper uses an ethnographic research methodology (Spradely 1979; Heritage 1984) and represents the findings from the viewpoint of the project managers. The findings from the project show that it was necessary for the project team to make sense of the implemented decision support system. The findings, furthermore, show that the project team needed to appropriate the system to the local project environment and the social system of the project team to the use of the system. I show how these mutual adaptation processes are influenced by the outcomes of the sense-making processes of individual project team members.

Chapter 3 represents an in-depth literature review of the related information system management, organizational science, and sociology literature. The chapter derives a theoretical grassroots model that explains, but also extends the findings from the case study. The theoretical model explains how members of project teams make sense about a decision support system that they implement and how technology managers can influence this process as fashion setters. By theoretically showing how project team members make sense of a technology and consecutively adjust the technology to their local social system and their social system to the technology the theoretical model gives new insights about organizational change and choice. Furthermore, the model explains how project team members individually and the project team as a whole influence the grassroots implementation. The theoretical model thus spans two organizational levels and complements organizational multi-level theory. Finally, this chapter complements information management science by deriving a number of managerial implications from the theoretical model which makes this chapter especially useful for technology managers of project-based companies.

Chapter 4 presents a technology research and development methodology to inform the design of technologies to support the work of project teams working on projects. The research methodology combines action research and ethnographic observations and thus complements existing project-centric research methodologies. I present the findings from successful applications of the research method on a number of projects that my colleagues from the Center for Integrated Facility Engineering of Stanford University and I conducted. Overall, this chapter is targeted towards technology developers who plan to implement technologies to support projects.

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2 Developing a Grounded Theory of Decision Support Implementations from the Grassroots of a Project Team

2.1 Abstract

This paper examines the implementation of an information system to support effective decision making within an organizational group with a flat formal power structure. During this qualitatively investigation of the implementation of the decision support system by a construction management project team we observed a grassroots implementation driven by the members of the project team working at the operational level. Based on this observation this paper develops grounded theory that explains such grassroots implementation processes using actor network theory. The paper explains how organizational members at the operational level make sense of the decision support system during the implementation effort, and how they utilize the system accordingly. Theoretical conclusions emerging from our findings show a bottom-up emerging process that we call un-black-boxing during which the project team defines the subjective spirit of the decision support system that describes how the project team perceives the benefits of the system and how it thinks the system can be best used on the project. How well this emergent spirit describes the objective technical reality prevailing on the project, then, in turn, influences how effective the project team uses the decision support system. The existence of bottom-up emergent grassroots processes challenges existing top-down technology management theories and, therefore, can help to further the understanding of project managers and technology managers of project-based companies.

2.2 Introduction

"When you are guided to any construction site you are experiencing the troubling and exhilarating feeling that things could be different, or at least that they could still fail – a feeling never so deep when faced with the final product, no matter how beautiful or impressive it may be" (Latour 2005: 89).

Latour uses this metaphor of a construction site to motivate sociologists to look at how new social systems are constructed instead of merely observing established stable social systems. In this paper, we take Latour's metaphor further and observe the creation of a social system around a newly introduced technology within the complex environment of a construction site. In general, people that work on construction sites build highly unique products. Since there are only limited opportunities to prototype buildings, the first real production attempt at full scale needs to result in an operational building. In such an environment, people need to rely primarily on tacit knowledge as few of the processes necessary to construct buildings can be explicitly assessed and converted into routines (Kreiner 1995). To cope with the complexity, construction companies typically organize their workforce around projects that are detached from the formal hierarchical structure of the company. They use projects because no explicit routines exist and, thus, there is little possibility to control the work of employees. As a result, corporate management needs to rely on the experience of its staff working at the operational level instead of relying on formal hierarchical structures to set up and carry out the processes needed to complete the project. These processes also include the selection and implementation of technologies to support decision making and communication. Such technologies integrate, manage, and visualize information from various data sources and can greatly improve the work of the members of project teams on the complex tasks that are prevailing in project environments (Majchrzak et al. 2000).

However, the management and implementation of such decision support systems seems to be more difficult in project organizations than in traditional hierarchical organizations (Gann & Salter 2000; Dubois & Gadde 2002). One challenge that is often referred to, is that a single project often includes different project teams. As a result, the strategies of these different teams need to be aligned (Taylor 2005; Adriaanse 2007). Contrary to this inter-project team view, this paper focuses on the challenges of a single project team with implementing a decision support system. Problems with the implementation in single-company project team contexts arise because project teams are temporary organization detached from the company hierarchy. In such contexts top-down innovation management models do not apply well due to a number of reasons. First, the influence of a company's central R&D unit that evaluates decision support systems and then tries to implement the technology throughout the whole company is limited for two reasons. On one hand, it is hard for such an agency to support the highly unique and creative decision making tasks of project team members, i.e., the company's employees working at the operational level across multiple projects because adequate support of the implementation of decision support systems would require in-depth knowledge about local project conditions. On the other hand, such a high level agency lacks the power to control whether a decision was supported with information developed through the selected decision support system or using, for example, a piece of scratch paper lying next to the computer desktop of the employee. Thus, because top-down innovation management is problematic in project based industries, it is important for technology managers, but also for project managers, to also understand bottom-up emergent processes during which project team members make sense of new decision support systems and integrate them into their daily decision making. This paper's findings serve as a foundation to understand such grassroots implementation of decision support systems better.

To improve our theoretical understanding of such grassroots processes, we conducted a qualitative field study investigating a construction project team implementing a decision support system. This paper reports our findings and develops a grounded theory of the grassroots implementation processes that we observed on the project. The developed theory enables readers to gain a better understanding of how project team members that work at the operational level make sense about the implementation of a decision support system and use the system according to the outcomes of these sense-making processes. This better understanding will help project team members that intend to implement a decision support system to better understand the implementation challenges. Furthermore, technology managers can use this better understanding of the sense-making process to support non-mandated bottom-up decision support system implementations on the projects of their company.

The paper is organized as follows: The first section frames the boundaries of the grounded research with a short introduction about decision support systems and project teams. In the second section, we describe our qualitative research design and approach. The third section describes the findings of our almost two year long field study during which we observed the implementation of a decision support system by a construction project management team. The fourth section uses structuration theory (Giddens 1986; Barley 1986; Orlikowski 1992), social sense making theory (Berger & Luckman 1990), theory about power structures in flat hierarchies (Foucault 1995; Barker 1993; Pfeffer 1992), and actor-network theory (Latour 2005) to ground our observations. The theoretical analysis in this section explains how project team members develop a subjective spirit of the decision support system in a process that we term un-black-boxing. This spirit describes the project team's mutual perceptions of the benefits and how the project team thinks the system can be best used on the project. We found that the size of the gap between the subjective spirit and the objective technical reality explains how well the project team can use the system. Finally, the last two sections summarize our findings and theoretical contributions and discusses the limitations of our work.

2.3 Decision Support Systems and Project Teams

Due to the nature of producing one-of-a-kind products, work in project-based industries, such as construction is characterized by a constant change of work tasks and requirements (Cohen & Bailey 1997). The highly reciprocal nature of these work tasks (Thompson 1967; Gann & Salter 2000) requires actors to rely on feedback from peers, clients, and the environment (Kreiner 1995). Work tasks in such environments are therefore highly complex (Baccarini 1996).

Therefore, many types of technologies that increase the productivity for other industry sectors are less useful on projects. For example, technologies that enable the storage of historical data are of less value for project-centric firms because data that might be stored by one project team will most likely not be useful for other project teams because these teams often have to build a significantly different building. Technologies that automate tasks are rare in project-based industries because the development of such technologies would require system developers to capture work processes explicitly. Such explicit capturing of work tasks is difficult because most of the knowledge only exists tacitly in the minds of the construction engineers.

Contrary to the systems described above, decision support systems are well suited to improve individual and organizational performance on projects (Gann & Salter 2000). Decision support systems use complex project information as input and visualize this information so that project team members can easily understand it. Furthermore, decision support systems support the communication on the project by distributing information to specific members of the project team that are responsible for making certain decisions.

Decision support system implementations by project teams are often a complicated task as a result of at least four intertwined complications caused by the characteristics of project teams and decision support systems. First, decision support systems consist of a bundle of software, hardware, and processes that can be used in different ways (Bidogli 2003; Gutek et al. 1984; DeSanctis & Poole 1994; Rice & Rogers 1980). Thus, it is often not clear how to configure software, hardware, and processes to solve tasks. Furthermore, the application of different configurations can often lead to the same outcome, or the use of the same configuration can result in different outcomes. Second, the effective use of decision support systems can hardly be mandated by upper management. Even if project team members have the opportunity to readily use a decision support system, they can continue to make decisions without using the system. There is no easy way for upper management to control whether or not a system is used efficiently. Third, due to the highly reciprocal nature of project tasks, project team members are dependent on information updates from other members (Gann & Salter 2000; Thompson 1967; Jin & Levitt 1996). Therefore, the successful implementation of a decision support system by a project team depends on a high level of integration of the system within the team. Fourth, a project team is a temporary organization without a “history or a future” (Kreiner 1995). It is assembled at the start of a project and will be abolished after the project has been completed. Therefore, project teams have only limited time to develop procedures about how to use the decision support system, and how the members of the team define various facts about the decision support system will vary throughout the project. A stable institutionalization (Scott 2001) of the use of a decision support system is unlikely.

To cope with these complications during the implementation of a decision support system, project teams need to align their work processes not only with the features of the technology but also with the social structures of the organization (Rice & Rogers 1980; Rogers 2003:181; Ives & Olson 1984; Clark 1987; Leonard-Barton 1988; Poole & DeSanctis 1990; Orlikowski 1992; Sokol 1994). Such alignment processes have been described for the implementation of a number of different technologies in different organizational settings. Barley (1986), for example, shows how doctor, nurse and technician teams in hospitals synchronize their use of CT scanners. Orlikowski (1996; 1992) describes the implementation of a system to track customer calls within the customer support center of a large software company, developing a theory that describes the implementation of productivity improvement tools for software developers. Majchrzak et al. (2000) show how a distributed project team used collaboration software during project management. While all these studies identify several key sources of complication, we are not aware of any study that captures all four complications we described previously. For example, in Barley’s study CT scanners are implemented into the relatively stable organization of a doctor/technician team. The same is the case for Orlikowski’s (1996) study of employees of a customer support center. In both studies, the organization existed long before the technology was implemented and will most probably exist after the technology has been replaced. Therefore, prior to the implementation of the technology stable working routines existed that structured the work tasks of the organizational members. Project teams that are formed to work temporarily to develop a one-of-a-kind product do not have such a common history and thus have no strong previous working routines developed. The Majchrzak et al. study comes closest to cover all the sources of complication derived above by describing the implementation of a technology by a project management team. However, the technology they describe is a collaboration tool that enables collocated members of a project team to communicate effectively. The description of the implementation processes and the theory building by Majzchrzak et al., therefore, do not focus in detail on how the project team members use the technology for their decision making tasks.

Our study describes a case in which all four sources of complications are present to advance our understanding of technology implementation processes in such situations. In the next sections, we will describe this case in detail and present the empirical research methodologies that we used to collect and analyze data.

2.4 Research Method

This study presents primarily a search for explanation and theory rather than just a report for empirical research. We were interested in understanding the complex social and technical reality that project teams face during the implementation of a decision support system. To allow such explanatory research, the first author of the paper became a participant observer on one large construction project for two years. This section explains the research method and the case for this participant research in detail.

2.4.1 The Research Setting

We conducted our field-study on a major subway re-construction project in a metropolitan city. The main goal of the project is to connect seven subway lines to ease the transfer of passengers between different lines. The project's scope includes the construction of a station terminal that allows access to different subway lines from the street level and that provides space for a number of shops and restaurants catering to subway passengers. Because the project is located in a congested metropolitan area, some of the subway lines to be connected serve more than 200,000 passengers a day.

Our study began when the project was in the design phase. The subway department hired an international design company to design the whole project. At times, more than 100 of the company’s design engineers worked on the project. Additionally, the design company outsourced several design tasks to sub-consultants. The subway department also hired a consulting construction management (CCM) team which represents the study’s organizational unit of observation. The CCM team is a joint venture that two international construction management firms founded to specifically work on this project. Few existing routines existed at the beginning of the work of the CCM team because the team was comprised of employees from two different companies that had never before worked together. The CCM team also had no joint future, i.e., the team will be dissolved at the conclusion of the project. Furthermore, due to the organization as a joint venture that operated independently from the two construction management firms, the CCM team was largely detached from the formal hierarchical structures of the two construction management firms.

The CCM team's organization was characterized by a very flat hierarchy. Officially, the project team was lead by a project director under whom a number of project managers worked. Despite this two level hierarchical structure, the project managers, however, were responsible for making their own decisions with respect to most of the CCM team's working tasks. The role of the project director was mainly limited to communicate the project managers' decisions to the other project stakeholders. Additionally, the work of the project managers was supported by a number of office engineers, who, though they formally reported to the project managers, were expected to work independently on tasks.

The CCM team had two major responsibilities. The first was to develop a packaging plan that allowed subcontractors to handle different parts of the construction. Packaging was necessary because of the breadth of the construction project no single construction company could carry the risks involved to construct the whole project on its own. In addition, the subway department anticipated that different contractors specializing in specific areas of construction could work on complex parts of the project, such as excavation, above ground construction, or below ground construction individually. On construction projects of this size, it is not an easy task to split the project into clearly distinguishable packages. For example, the spatial and temporal intersections between the different packages need to be closely analyzed to avoid conflicts and gaps between different contractors during construction. Such conflicts usually arise when two contractors claim the same space at the same time in an attempt to accomplish necessary work. Of course, within the highly congested area of a metropolitan city, this problem is further complicated by a general lack of space for storing construction materials or for setting up temporary construction machinery, such as cranes, excavators, or pile drivers.

The CCM team distributed their work on the packaging plan among a number of different project managers. Each project manager was responsible for one of the anticipated packages. During planning, however, the anticipated boundaries between the different packages shifted constantly. Therefore, each of the project managers was reciprocally dependent on information input from each of the other managers. The reciprocal character of the packaging effort was furthermore heightened because one of the goals of the packaging effort was to minimize possible conflicts between the packages.

The second responsibility of the CCM team was to determine whether the design could be implemented in the congested metropolitan area while operating all seven subway lines continuously throughout the duration of the project. During this so called constructability review, the CCM team was highly dependent on information input from other external organizations, such as the design company or the client organization. The CCM team, additionally, needed to communicate the outcomes of the constructability review to the designer and the client organization. Thus the work of the CCM team was characterized by a constant stream of information between the CCM team and other outside organizations. Finally, as the work of the CCM team started before the design had been finalized, different aspects of the design changed frequently and, therefore, the CCM team's work tasks and the tasks' priorities changed often. Summarizing the above, the CCM team represents project team characteristics well, especially the temporary nature, the detachment from the formal hierarchy of the company, and the highly reciprocal nature of work tasks.

The CCM team decided to utilize a decision support system to understand all these project complexities better. This system, a so called 4D application, was designed to simulate the planned reconstruction sequence, starting with the existing conditions at the construction site and ending with the proposed final conditions of the project. As an input to the 4D system, geometrical 3D computer models are necessary that represent the site before the start of construction, that represent the anticipated conditions after construction, and that represent any temporary conditions in between. Furthermore, one needs construction schedules that represent all the planned construction activities with corresponding estimated durations. Throughout our observations on the project, the CCM team generated 3D computer models of the existing and the proposed conditions that reflected current states of the ongoing design activities and a number of schedules that reflected the current construction plans as anticipated by the CCM team's project managers. The CCM team then used the 4D application to link the schedule to these 3D models. This link then enabled the 4D application to simulate, visualize, and automatically analyze various alternative construction work sequences and construction schedules. The CCM team hoped that the 4D application would help them understand the project better than traditional methods that implied to imagine how different construction sequences would play out using only 2D drawings of the existing and proposed conditions and schedules.

One can characterize the 4D application as a typical decision support system. It is comprised of a bundle of different features (Gutek et al. 1984; DeSanctis & Poole 1994; Rice & Rogers 1980), such as color coding functionalities that distinguish between different types of work activities, or different features to simulate the construction sequence, including a time slider function or a calendar function that enables engineers to view the state of the project site at any point in time. Furthermore, the 4D application offers several features to navigate and slice the 3D representation of the facility in different ways thus allowing engineers to generate cross-sections showing any location of the project at any point in the planned schedule. Due to the myriad of possible features it was not clear to the members of the CCM team which of the features to use for which tasks. Complicating the situation even further, several different features could lead to the same solution. Thus, the members of the CCM team needed to appropriate the features of the 4D system to fit the context of the constructability review tasks at hand.

In addition to the different features of the 4D application itself, the overall 4D system was comprised of a loose bundle of different software applications and hardware (Bodgoli 2003). To create the 3D models that are required as an input for the 4D application, 3D modelers on the project used four different 3D modeling applications. Furthermore, project managers used two different scheduling applications to generate the schedules that served as the second input for the 4D application. 3D models and schedules were stored on two different file servers, one that was located in the office of the 3D modelers and one that was located remotely, but that enabled online access to 3D models and schedules. As 3D modeling is a computation intensive work task, the 3D modelers were equipped with special CAD workstations that were more powerful than the other project team members' computers. Finally, the CCM team acquired laptops and a projector to visualize the 4D models in meetings with other project stakeholders.

Another typical feature of decision support systems that characterizes the 4D application is that its successful application depends on the level of integration within the CCM team. Especially during packaging it was important that 4D models represented information that was created by various project managers that were responsible for different packages to visualize the construction work at the important intersections between the packages. Thus, the outputs of the 4D system were only meaningful for decision support if the inputs to the system represented information developed by a number of different project team members. Summarizing, to make the outputs of the 4D system meaningful different members of the team that are knowledgeable about different aspects of the construction need to jointly contribute to the inputs of the 4D system.

To achieve this required integration within the project team was complicated as it was not easily possible to mandate the use of the system. Despite the fact that the CCM team's client financed the use of the system and, thus, expected the CCM team's project managers to use it, project managers could easily circumvent this mandate because of two reasons. First, due to the flat hierarchy of the project team, project managers did decide what tools to use to support their decisions by themselves. Few formal structures were in place that the client could apply to enforce the use of the system. Second, it was impossibility for the client to control whether a decision was made using the 4D system or not. It was easy enough for the project team to use the client's money and generate 4D simulations that only reflected ready made decisions project managers had made using other tools. In summary, the study of the 4D system implementation by the CCM team is poised to further our understanding of grassroots implementation processes as all sources of complication that we derive in the previous section are present.

2.4.2 Data Collection

We collected the main part of the data for this paper during a one year participatory field study (Jorgenson 1989; van Maanen 1988; DeWalt & DeWalt 2002). Our entrance to the field was initiated by the R&D department of one of the joint venture companies that hired the paper's first author to support the CCM team in implementing the 4D system. The CCM team knew about the affiliation of the first author with a renowned research institute and of the intention of the first author to conduct fieldwork research on the project. However, at the start of the fieldwork we did not intend to address the problem of sense-making processes during the implementation of a decision support system. Therefore, our research objectives, in hindsight, were not overtly communicated to the CCM team whose members believed, at least at the beginning, that we intended to inform 4D system development with ethnographic research.

During the fieldwork the first author of the paper tried to become as integrated in the CCM team as possible. Throughout the year in the field, the first author of the paper spent every work day with the team, trying to get as involved in the daily project management work as possible. Doing so, the first author pro-actively took on project management tasks that exceeded his initial work assignments of supporting the CCM team with the implementation of the 4D system. The first author also took part in the non-work related rituals of the project team, like going for drinks on Friday afternoons, company parties, or other social events. One indicator for the success of the first author at integrating himself as a full team member was the CCM team's decision to pay the first author for another six months out of the project budget after the initial funding from the R&D department ran out. The first author was able to become a full member of the CCM team and gain the trust and cooperation of the project team. In turn, he was able to normalize his presence as a researcher, which enabled him to observe and describe the team's work culture accurately, objectively, and truthfully from the team's perspective (Jorgenson 1989:56). Additionally, the direct involvement enabled the author to gain in-depth knowledge of the 3D/4D system and its implementation which would not have been possible otherwise. Similar to Becker in his classic study of jazz musicians (Becker 1951) who learned how to play jazz music to be able to better analyze the social life of jazz musicians, the first author learned how to use the 4D system in the practical context of the CCM team. Therefore, the direct involvement with the team enabled us not only to better account for the team's culture, but also for the technological aspects of the implementation.

After the first year of research, the first author left the project. The CCM team erroneously believed that, at this point in time, it was able to use the system effectively without the help of the first author. They decided to stop funding the researcher's work. As mentioned earlier, the problem that we address in this paper only emerged after we left the field. Fortunately, the previously established intimacy with the CCM team allowed us to remain in close contact with the project. This enabled us to complement the experiences we gained during the fieldwork by specifically collecting data about issues related to the research problem. The CCM team granted us access to all of their electronic documents so that we could follow the team members' electronic communication and the generation of new 4D models without being physically present in the field. Additionally, the first author traveled seven times to the project and conducted follow-up ethnographic interviews (Spradley 1979) with a number of project team members and observed their work for a number of days during each trip. The second phase of data collection was very valuable to gain a better understanding about our research problem. Furthermore, because of the physical and intellectual distance to the field we could reflect about our theoretical questions more objectively. These reflections, in turn, enabled us to specifically follow up on the initial data collection by formally interviewing project team members and by referencing the electronically stored documents of the CCM team. The next sub-section details how we developed theory.

2.4.3 Data Analysis and Theory Development

We started our fieldwork with a different problem definition in mind, so our data analysis and theory development processes were not as linear as they are often depicted by case study researchers (Eisenhardt 1989; Yin 2003). We frequently iterated problems that we addressed and only slowly arrived at the final problem that we address in this paper. As mentioned, we intended to inform the technical development of the 4D system with ethnographic observations at the beginning of our fieldwork. However, after some time on the project we slowly understood that the technology itself was only a small part of the problem that the project team faced during the implementation. Thus, we started to refocus our attention on researching organizational processes and how these influenced the implementation. After exiting the field and after reflecting on our experiences, we finally arrived at the insight that we need to understand the team members' sense making processes during grassroots implementations to understand decision support system implementation by project teams better. Despite the presentation of much case study research as a linear process of defining a problem, entering the field, and analyzing the field data, the definition and redefinition of research problems in this way lies at the heart of every participatory observation effort (Jorgenson 1989:18). Often, during fieldwork, initial research questions might make no sense in the daily realities of life (Jorgenson:23). Thus, it is important for researchers to constantly reformulate the problem under consideration (Jorgenson: 34). Fieldwork not only begins before one enters the field, but also ends long after one has left (van Maanen 88:117).

The constant redefinition of our research questions throughout our involvement with the project influenced our data collection and analysis methods. Following sound participatory research methodology we collected data from different sources while we were in the field. We jotted down terse field notes in a number of notebooks that we regularly converted into more formal diaries. Furthermore, we collected a large number of documents during our field work and in the second phase of data collection, like electronic communications, meeting minutes, or presentations (the appendix of this thesis lists an inventory of the data we collected). One tool that proved to be very helpful during our early and ongoing problem definition and, in hindsight, for our later data analysis turned out to be the work on a number of research report drafts throughout our fieldwork. Those drafts helped us to understand the project better and served, as mentioned by Jorgenson (1989:105), as a valuable substitute for the often irregular and unsystematic note taking that was caused by the emerging problem definition. In the meantime, revised versions of these drafts have also been published or accepted for publications in major construction management journals (Hartmann & Fischer 2007; Hartmann et al. forthcoming).

While analyzing the collected data to develop the constructs we present in this paper, formal data coding (Bazeley & Richards 2000; Strauss & Corbin 1990; Glaser & Strauss 67) was not always possible due to two reasons. First, the most important data that we collected were our observations and experiences that we jotted down as field notes. However, due to the shifting research questions, our field notes are irregular and inconsistent with respect to a coherent problem focus. Thus, the notes do not lend themselves well to formal coding. Second, the wide variety of different data sources and the sheer amount of available data required us to rely more on our common sense and memory than on formal data coding methods. Overall, we faced the same problem that van Maanen (88: 131) describes so vividly: “To put a theoretical scheme to work crunching texts, requires text to be put in crunchable form.” Unfortunately, we were not able to convert our notes and other information sources into a “crunchable text“ that would have allowed formal qualitative data analysis. Again, however, this approach is not uncommon for participatory fieldwork studies, as much of the data may not be useful for a specific report (Jorgenson 1989:122) and common sense - instead of formal methods - is still the best basis for creative development of formal theories (Jorgenson 1989:114).

While we did not apply a more formal analysis method using qualitative data coding techniques, our field notes, diaries, and draft reports helped us to prime our memory to reconstruct the events we experienced on the project in the order that they occurred. We then triangulated our reconstructed event history with the other documents we collected. Triangulating the interview data with the electronic documents we collected allowed us to reconstruct the events for the period of another year after we left the field. By doing so, we gained a retrospective view of how the implementation of the 4D application unfolded over time. We specifically analyzed the kinds and frequency of different 4D system utilizations by the project team. To visualize the occurrences we mapped positive reports of the project team members' use of the 4D application within our field notes and the other documents along an axis (Figure 2-1). Even though the work tasks of the project team throughout the observation period were relatively stable – as mentioned the project team was responsible to evaluate whether the design was constructible and how to best package the work - the figure indicates six different phases of varying intensity for the utilization of the 4D application. We started to analyze the data for each of these phases to identify the main actors that were responsible for the utilization or non-utilization of the 4D application. Then we analyzed our data to find clues of how the sense-making processes of these project team member's took place and influenced the use of the 4D system in each of these phases.

Throughout the process of analyzing the data we used Jorgenson's (1989:110) and van Maanen's (88:66) suggestions to consult literature and theories to relate to our emerging patterns. Therefore, while our explanations of the events on the project closely reflect our experiences and data, they are additionally informed by formal theories. We then started to describe our findings using an actor network theory (ANT) framework. The next sub-section explains our description method in detail.

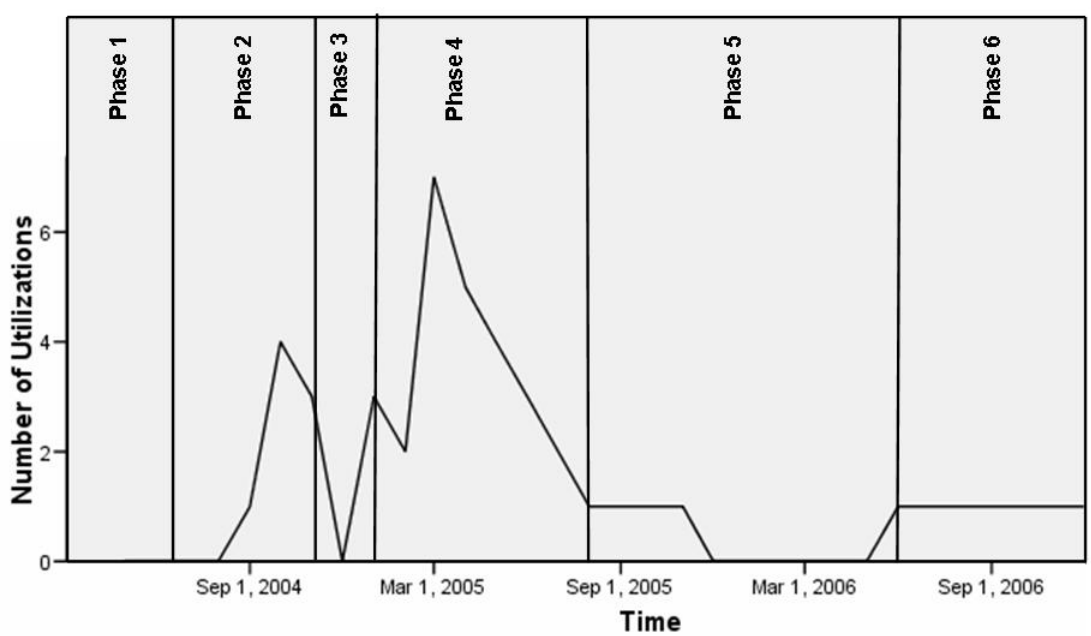

Figure 2-1 - Number of Applications of the 4D System and Phases (monthly data

points for phases 1-4; data points from Aug 05, November 05, July 06 for Phase 5; data points from February 07, March 07, May 07, July 07 for Phase 6)

2.4.4 Result description

To describe the findings of our empirical study we use actor-network theory (ANT). ANT provides a valuable analytical lens through which to observe the mutual relationship between technologies and organizations within complex environments (Holmstroem & Robey 2005). ANT requires authors to describe four social factors that are usually ignored in sociological accounts but that are necessary for understanding complicated situations (Latour 2005: Chapter 1). First, ANT studies describe the formation of groups instead of groups that are already existing (Latour 2005: Chapter 2). Therefore, ANT explains the complicated dynamics in the temporary established CCM team. Second, ANT focuses on how actors take over different actions instead of simply analyzing the action itself (Latour 2005: Chapter 3). Thus ANT explains how CCM team members chose to use different features of the 4D system independently and without higher level mandates. Third, ANT focuses on identifying the different concerns that actors have with the matters at hand instead of considering occurring matters as facts that all actors in an organization regard equally (Latour 2005: Chapter 5). Thus, ANT is well suited to analyze how CCM team members chose to use specific features of the 4D system to help complete their daily tasks. Finally, ANT allows the researchers to analyze the role of objects in organizations. Thus, ANT helps us to describe the effects that the 4D system had on the social structure of the CCM team (Latour 2005: Chapter 4). Additionally, ANT supports the description of the 4D system's level of integration in the CCM team.

Accordingly, we will use ANT to report our observations of how CCM team members and actors from outside the team affected each other and the 4D system in their efforts to successfully implement the technology on the project. In doing so, we will show how the 4D system not only diffuses through a group of passive CCM team members, but how CCM team members that decided to be part of the implementation process needed to invest their energy to transform the 4D system so that it works within the local project context (Latour 1986). Using terms from actor-network theory, we call this investment of energy by project team members "enrollment"[1]. Following Callon's (1986) advice to choose one system of actors, we will try to describe how the CCM team members interpreted the different events that were

[1] Michel Callon introduced the term enrollment to actor network theory in 1986 in his seminal book chapter "Some elements of a sociology of translation." Though the term sounds awkward at times, we decided to use the term in accordance with Callon throughout this paper to stress the CCM team

related to the 4D system from their point of view. We restrain from using pre-defined roles and fixed role assignments for all actors. Instead, we show how the CCM team members supported and translated different aspects of the 4D system implementation into their own language by enrolling themselves as spokespersons for different 4D system related programs (Callon 1986). Finally, during our description of the implementation, we consider the 4D system as part of the CCM team's network that is able to socially influence the CCM team members. We achieve this by using the same vocabulary for describing the "actions" of CCM team members and the 4D system (Callon 1986). Equipped with the ANT techniques, we organize the data and present our findings in the next section.

2.5 Rhetorical 4D, Technical 4D, and Translation between the Programs

Our findings show that the 4D system influenced the members of the CCM team in two distinct ways that we refer to as programs. The first program describes the objective technical reality of the 4D system implementation on the project. The human actors on the project were influenced by interacting directly with the technology. In addition to the technical program, a rhetorical view of the 4D system existed that served as a "plug-in" (Latour 2005: 204) that the CCM team members used to communicate characteristics about the 4D system and its implementation. This rhetorical 4D program can be best described using Callon and Latour's notion of the "black-boxing"[1] (Callon & Latour 1981: 279; Mouritsen & Flagstad 2005). In our specific context, black-boxing means that actors on the project simplified the 4D system into an easy to understand rhetorical 4D program by metaphorically stressing certain positive or negative facts about the system while neglecting other facts. In this way, the actors reduced the characteristics of the 4D system to a number of well-defined parameters (Callon 1987). By black-boxing the 4D system, the CCM team was able to substitute the complexities of the 4D system with easily understandable concepts. By comparing the statements of the CCM team members with observations of how they used the system our findings show that this rhetorical 4D program was not a simplified aggregation of the technical 4D program because the rhetorical program often included concepts that did not represent the technical reality. Therefore, we treat the two programs as two separate figurations (Latour 2005:54, 199) of the 4D system that both influence and are influenced by each other and the member's of the CCM

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member's active engagement with the 4D system.

[1] Again we use the term "black-box" in accordance with ANT. Callon and Latour (1981:285) describe a black box in detail: "A black box contains that which no longer needs to be reconsidered, those things whose contents have become a matter of indifference." In his later work Latour (2005) also

team.

During the following description we analyze the gap between the two programs for each of the six implementation phases (Figure 2-1). We do so by comparing statements of actors and observations of the utilization of the 4D system. Furthermore, we show that to use the 4D system within their daily work efforts, the members of the project team had to constantly translate between the two 4D programs (Latour 1986). We show these translation processes for six distinct implementation phases on the project.

2.5.1 Phase 1 – Initial Struggles

During the first phase of the 4D system implementation, the CCM team was not able to successfully translate between the rhetorical and the technical 4D program and, as a consequence, the CCM team members could not use the 4D system during their daily work. Table 2-1 summarizes the most important actors in this phase and their efforts to enroll and translate between the programs.

In the beginning of this phase, a corporate technology manager (Technology Manager) from one of the joint venture companies established contact with the team. The Technology Manager tried to convince the CCM team to use the 4D system on the project. Initially, the members of the CCM team were very skeptical of an implementation of the 4D system. An email from the Technology Manager illustrates this well:

I had long conversation(s) with [the project director] and a few folks yesterday and we need to make sure these guys are more comfortable than they currently are. Too bad they didn't attend your brown bag presentation because they want to know what specific things your previous projects actually did to identify/solve specific problems. Do you have anything convenient that lists specific benefits on real projects? I guess my examples and generalizations are too general.

Email from the Technology Manager from April 22, 2004[1]

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uses the synonym “plug-in” instead of “black box” (Latour 2005:207).

1 We disguise all names of actors, locations, or objects that could be used by readers to identify individuals from the project in all extracts from the field notes, electronic documents, or interviews we use as evidence for our findings.

Enrolled Actor	Rhetorical 4D	Translation to Technical 4D	Used Enrollment Devices
Technology Manager	"4D scheduling provides the ability for many people from different disciplines and with different expertise to see the project and schedule in a common format that everyone understands." "10 Pts why to use 4D on the project."	none	Slideshow presentation of other projects that used 4D systems
University Professor	"We successfully helped to implement 4D systems on a large number of other projects" "Build it in the computer before you build it on site […]it is cheap to make mistakes and changes in the computer"	none	Credibility of the university and professor status
Visualization Company	"Will deliver the first 3D models to be used with 4D within two weeks" "We will be able to use most of the already existing 3D models that the designer created"	Internal struggle with file formats, manpower resources, and software programs	Reputation as one of the leading visualization companies in the metropolitan area
4D System Software Company	"Our software works seamlessly together with 3D models" "… [our software] includes features to easily and flexibly link your 3D model and project schedule, customize 4D playback, and easily view, share, and analyze your 4D models with all project stakeholders."	3D models need to be in a specific file format so that they can be used by the 4D system For a successful use of the 4D system the 3D models need to be a very detailed representation of the project	4D software system and several converters between different 3D model formats
Project Managers	"When will the first 4D models be available?" "If the system will not work soon we have to pull the plug and stop the 4D effort!"	none	Rational needs to work on the day-to-day project management tasks

Table 2-1 - Actors, Enrollments, and Translation in Phase 1

In one of the meetings between the Technology Manager and the CCM team, one project manager requested “ten good reasons why we should use this on our project.” In response to this request, the Technology Manager generated a slide show with ten points on how the 4D system could help the CCM team with their work. This slide show listed the way other projects had applied the 4D system in the past (Figure 2-2). The reasons on the slides were very general and did not focus in detail on how the CCM team could utilize the technology to work on their local tasks. However, the presentation convinced the members of the CCM team to use the 4D system. The CCM team decided that a request should be made to the subway department to request additional funds to finance the implementation of the 4D system.

10 Reasons to Use 4D Scheduling

1. Better communication and coordination with all project participants
   - Client – Other Agencies – Design Consultant - Partners – Subs – Public
2. Early identification of problems before they become costly field errors / changes
3. Include Resource / Sub contractor information to see “where” people are working
4. Visually delineate and track work packages at Program, Project, or Task level
5. More accurate analysis of the impact of potential changes and the development of work around solutions
6. Compare alternative schedule/build sequences visually for “what-if” scenarios
7. Compare planned versus actual schedules to visually see where discrepancies exist
8. Include cost and resource information to visually identify and forecast when and where costs are occurring.
9. Visually analyze and communicate work staging areas and site logsitics.
10. Visually identify any P3 / Expedition data when and where it occurs
    - RFI's, Change Orders, Pay Requests, Action Items, Documents, Reports

Figure 2-2 - Slideshow "10 Reasons to Use 4D Scheduling"

In preparation for this presentation to the subway department, the Technology Manager enrolled another actor to support the credibility of the presentation. This actor was a renowned professor from a large university that had spearheaded the development and practical application of 4D systems on a number of construction projects in the past. Together, the CCM team, the Technology Manager and the professor (University Professor) were able to convince the subway department to finance the implementation of the 4D system. Unfortunately, both the Technology Manager and the University Professor were unable to enroll in the technical 4D program at this stage. This was mainly due to their consultant statuses and the fact that they were usually not physically present on the project. Both actors visited the CCM team only a small number of times without being involved in the team’s day-to-day activities. As an additional support for the technical 4D program, the Technology Manager therefore enrolled a computer visualization company to create the three dimensional (3D) models of the project facility that are necessary as a technical input to the 4D system.

This company had the reputation of being one of the most advanced visualization specialists in the metropolitan area, but had no previous experience creating visualization models for 4D systems. Nevertheless, the company promised to deliver the first 3D models within two weeks. However, the company was not able to translate this rhetorical promise into technical reality due to a number of reasons. First, the success of the company was mainly based on the 3D modeling skills of the founder who used an outdated modeling software system that was not compatible with the 4D system the CCM team used. Therefore, additional effort was necessary to transfer the founder's 3D models to the 4D software. Due to the small size of the company and the workload from other projects, the visualization firm was not able to commit the required resources to solve this technical problem in a timely manner. Second, the visualization company had planned to reuse a number of 3D models that the design company had already generated. However, these 3D models were created with a very coarse level of detail for the purpose of photo-realistically visualizing certain aspects of the planned design of the project. Due to this coarse detail these existing 3D models were not adequate to support detailed project management tasks.

After a while, it became clear to all participating actors that the visualization company would not be able to translate their rhetorical promises into a technical 4D program in a timely fashion. Therefore, the Technology Manager and the University Professor enrolled yet another actor to support the necessary translation: The software company that sold the 4D system. Representatives of the software company visited the project a number of times and worked together with the visualization company. However, the representatives of the software company were mainly experts in the use of the 4D system and not experts in the creation of 3D models. Therefore, the work of the representatives of the software company was rendered meaningless as well. In the end, the translation efforts between the rhetorical and the technical 4D program in this phase failed as the gap between the two programs was too large.

Due to the failed translation attempts the CCM team could not use the 4D system within this phase. This caused two main problems among the CCM team members. First, the CCM team members perceived limited control over the implementation of the 4D system. This lack of control was especially evident in the outcomes of weekly 4D meetings that the CCM team scheduled. CCM team members continued to brainstorm how the 4D model could help them within their daily work referring to the ten points presented earlier by the Technology Manager. However, the discussions within the meetings were meaningless due to the lack of existing 4D models. The CCM team members quickly realized this problem: They began to ask "when will the system be available?", being largely ignorant of the technical difficulties the visualization company and the software vendor company were negotiating. This technical ignorance, in turn, prevented the project managers to enroll in the technical 4D program.

The second CCM team members' problem occurred when they realized the large gap between the rhetorical and the technical 4D program. This realization caused the CCM team members to become intimidated about the 4D effort with respect to the promises they had made earlier to the subway authorities. The CCM team set a number of deadlines indicating when the 4D system would need to be ready. The team members threatened "to pull the plug and stop the 4D system on this project", if these deadlines could not be met. The client was never informed about the problems, and deadlines continued to expire without the CCM team abandoning the 4D efforts. Finally, the Technology Manager and the University Professor decided to send a Ph.D. student on the project to support the 4D system implementation as a full-time member of the CCM team. The arrival of this Ph.D. student[1], henceforth referenced as the "4D Specialist", was the start of the second implementation of the project that was more successful than the first phase with respect to the use of the 4D system.

2.5.2 Phase 2 – Satisfying the Benefits

The beginning of this phase was characterized by the efforts of the 4D Specialist. He began to shape the rhetorical 4D program more realistically and he enrolled into the technical 4D program to solve technical issues that impeded the use of the 4D system. These efforts were partly successful, allowing the CCM team to enroll in the technical 4D program at the end of the phase. This enabled them to use the 4D system for some of their work tasks. This section describes the events in this phase in detail. Again we summarize the occurrences in a table (**Table 2-2**).

In the beginning of this phase, the 4D Specialist enrolled in the rhetorical 4D program to reduce the gap between the rhetorical program and the technical reality of the 4D system implementation. He started to explain to the members of the CCM team why more time would be needed to generate the 3D models. He explained the technical problems of the visualization company with the 4D software and that it was not possible to use the 3D models available from the design company. With these explanations, the CCM team understood why 3D models were not available yet, reducing the CCM team members' lack of technical knowledge.

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[1] This Ph.D. student is also the first author of this paper.

Enrolled Actor	Rhetorical 4D	Translation to Technical 4D	Used Enrollment Devices
4D Specialist	“We will need more time to create the 3D models” “The visualization company does not have the capacity to generate the 3D models as desired” “We will need to have construction schedules that can be linked to the 3D models”	Review of the existing 3D models from the design company Recruitment and training of in-house CAD operators to generate 3D models Created the first 4D model that supported project managers in their daily work	Technical know-how of the 4D system, 3D models, and construction schedules 3D and 4D model production schedule
Technology Manager	None	Helped to identify and recruit the in-house 3D modeling staff	Knowledge of one of the Joint-Venture’s companies personnel and organizational structure
Internal 3D Modeling Team	None	Created the first 3D models at the necessary level of detail and accuracy	3D modeling knowledge and ability to understand construction drawings 3D modeling software that produced 3D models that were compatible with the 4D system
Project Managers	“I was worried all weekend whether we can build the subway station while we maintain the required 11’ street lane for the traffic and you show this to me within 10 minutes. This system is great” “I was not aware that we cannot build a temporary road deck to maintain the traffic on one of the streets.”	First successful applications of the 4D models that the 4D Specialist provided	one-on-one meetings and project team meetings where the 4D system was used

Table 2-2 - Actors, Enrollments, and Translation in Phase 2

The 4D Specialist's enrollment into the rhetorical 4D program had the effect that the Technology Manager also enrolled into the technical 4D program. The Technology Manager realized that the visualization company did not have the capacity to establish the needed 3D models in a timely manner. Therefore, he decided not to continue to work with the visualization company. As an alternative, the Technology Manager used his personal connections within his company to identify in-house personnel that had experience in 3D modeling, and an understanding of the required level of detail needed to support construction management. He hired three experienced 3D modelers that enrolled as new actors into the technical 4D program. These 3D modelers were in-house staff, so the 4D specialist was able to train them to create 3D models that would work with the 4D system. Furthermore, these 3D modelers were already experienced in using 3D modeling software whose output was compatible with the 4D software system. Together with the 4D specialist, the 3D modelers established a 3D modeling schedule with expected delivery dates of 3D models of the different parts of the project. This schedule translated the rhetorical 4D program closer to the technical reality by offering an estimate of when the CCM team could expect to use the 4D system. The first 3D models soon became available and finally enabled the project managers of the CCM team to use the 4D system and enroll in the technical 4D program. The project managers started to successfully use the 4D system to solve a number of problems that occurred during their day to day work. To provide evidence of this successful use, we describe two application examples in detail.

In the first example, the 4D Specialist helped one of the CCM team's project managers (Project Manager A) with one of his working tasks. Project Manager A worked on evaluating whether it was possible to renovate a subway station while maintaining the traffic on the street above. To maintain the traffic and to perform construction work on the subway station below it was necessary to maintain an eleven foot lane and to create an opening in the street that was large enough to perform the necessary construction activities below. It was hard for Project Manager A to determine whether the eleven foot traffic lane could be maintained over the entire construction period by using the information that was provided on the two-dimensional (2D) design drawings. This problem occurred because the design company represented the street level and the subway station level in two different drawings. Therefore, Project Manager A was not able to simply determine the opening size required to install the subway station underneath using the station level drawing, nor was he able to determine how much of the street would be covered by the opening using the street level drawing. The 4D specialist realized that by using the measurement feature provided by the 4D system together with the 3D model that represented the street and subway station levels, he could provide a quick answer to Project Manager A's problem. In a meeting that lasted less than ten minutes, Project Manager A and the 4D Specialist were able to determine that the required eleven foot traffic lane could be maintained and was able to easily make the decision that the respective subway station design was constructible. With this understanding, project manager A was relieved:

*"**I was worried all weekend whether we can build the subway station while we maintain the required eleven foot street lane for the traffic and now we figure this out in 10 minutes. I wished that we would have used 4D already on Friday and I would not have worried about this all weekend long."***

Quote noted in the field notes on September 15, 2004

In the second example, the 4D specialist asked another project manager (Project Manager B) to look at the existing 3D models to ensure that the model adequately represented the planned construction work. Interestingly, this meeting turned into an actual project management meeting where the meeting participants discussed possible ways of how to construct a tunnel connecting two different subway lines underground. Before the meeting the CCM team believed that it was possible to construct a temporary road deck that would allow the maintenance of street traffic during the construction of the tunnel. However, during the meeting the CCM team realized that the space under the street level was not sufficient to construct the required steel support beams for the temporary road deck. Thus, the CCM team decided in this meeting that it was not possible to construct a temporary road deck. The following excerpt from the meeting minutes provides evidence for the decision finding process of the CCM team:

"[Using the 4D model] the team discussed and evaluated the restricted space conditions at the east end of the […] passageway on the intersection with the [subway line]. Within this area there is a mezzanine level above the passageway, restricting the area between the planned underground construction and the street. Due to the restricted conditions it will not be possible to construct a temporary road deck. The model showed that the beams of the temporary road deck would overlap with the proposed beams of the mezzanine level. However it might be possible to entirely close down [the street] for the construction that needs to be done under the east part of the road."

Meeting minutes published online on Nov 04, 2004

After this meeting, Project Manager B became one of the main supporters of the 4D system and enrolled in the rhetorical 4D program by informing a number of people about the power of the 4D system:

> *“**This tool is a great way to understand the design of the project better.”***
> *Quote noted in the Field notes on Nov 02, 2004*

These two examples show that during phase two the project team started to enroll in the technical 4D program and was able to use the 4D system to support a number of project management decisions making tasks. These enrollment and translation activities reduced the gap between the technical and rhetorical 4D program. Due to the smaller gap between the two programs, the members of the CCM team became more knowledgeable about the technical functionality of the software. Furthermore, their control over the application grew in this phase and replaced the feelings of intimidation that had occurred in the first phase. The project managers’ specific control was still relatively low. This low control is, for example, evident in the two application scenarios of the 4D system described above that were proposed by the 4D specialist. The project members were content in benefiting passively and did not yet involve in actively shaping the technical 4D program.

2.5.3 Phase 3 – Confusion

At the beginning of phase three, the subway department decided to change the design of the project significantly to stay within budget. Subsequently, the design company started a value engineering process to reduce the estimated costs of the project. During value engineering, many portions of the design were changed. These changes, in turn, rendered portions of the existing 3D models obsolete because they reflected the old design. This change triggered discussions among the project team members about the 4D system’s value. During these discussions, one of the project managers (Project Manager C) spread his negative opinion with respect to the 4D system through the CCM team. Consequently, the members of the team stopped using the 4D system despite the successful application of the system during phase 2. The rest of this sub-section retraces what happened in this phase. We summarize the main actors and their actions in Table 2-3.

As mentioned, at the start of phase three, the subway department decided to reduce the project’s cost as a number of construction cost estimates that were prepared by independent experts predicted a significant cost overrun. To reduce construction costs, the subway department mandated the designer to redesign the project through a value engineering process. The designer changed large parts of the previous design, rendering parts of the 3D model built so far obsolete.

To finance the re-modeling of the existing 3D models to reflect the new design, the CCM team would have been required to secure additional funding. This triggered a discussion within the CCM team concerning whether or not it would be economically legitimate to spend more money on the 4D effort. During this discussion, the members of the CCM team tried to evaluate the costs and the benefits of the 4D effort thus far and for the remodeling effort.

Enrolled Actor	Rhetorical 4D	Translation to Technical 4D	Used Enrollment Devices
Transit Authority	"The existing design will be too expensive to build. We will need to value engineer it."	none	Construction cost estimates from independent sources
Project Manager C	"The value engineering will change 70% of the previous design. To remodel this design in 3D will be expensive." "We have not yet accrued any benefits using the 4D model, so why should we invest the additional money?"	none	Legitimacy in the project team due to his experience in construction management
Project Team	None	Stopped to apply the use of the 4D system	none

Table 2-3 - Actors, Enrollments, and Translation in Phase 3

During this discussion, Project Manager C was able to spread his opinion through the CCM team. Project Manager C had previous project management experience on a number of the largest construction projects in the metropolitan area. Thus, Project Manager C was acknowledged amongst his peers as one of the more experienced and skilled project managers and his opinion was highly valued among the other CCM team members. His opinion can be best assessed by the following statement he made in a discussion with the 4D specialist:

"To be honest, I am not sure any longer whether it makes sense to apply a 4D system on a construction project. So far we spent more than $100,000 to create all these 3D models and we have hardly used them to support our work. I mean, yes we

looked at the model, but it is mainly pretty pictures that do not really help to make decisions. And now with the value engineering we would need to remodel 70% of the 3D and I do not see how this can be defended in front of the client who pays for it. The 3D modeling process necessary is simply too expensive for us as construction managers to do. "

Quote noted in the field notes on January 24, 2005

A triangulation of data shows, however, that this statement of Project Manager C did not reflect the technical reality in this phase particularly well. Though the design company had remodeled large parts of the initial project design half of the existing 3D models represented the conditions of the project site before the start of construction activities which the project team could reuse. Table 2-4 shows a summary of 3D model parameters that we extracted from archived 3D models. The table shows that to be able to continue using the 4D system, 3D modelers needed to remodel far less than 70% of the existing 3D models since 50% of the 3D objects in the 3D model existing at the time represented the existing conditions of the project which were not affected by the design changes.

Model Parameters	Existing Design	New design	Percentage Existing
# polygons	1,366,292	1,596,041	46.12%
# objects	25,253	19,458	56.48%

Table 2-4 - Size of Fulton Street models, existing and proposed structure

However, as Project Manager C was one of the CCM team's opinion leaders, the other team members also began to enroll in his rhetorical 4D program, supporting the opinion of Project Manager C. In consequence, the members of the CCM team became less knowledgeable about the reality of the 4D system. Furthermore, the CCM team members' level of intimidation regarding the system grew once again. On multiple occasions team members stated their concerns of how to explain the large amount of money the team had already spent on the 4D system to the subway department. The team members began disengaging from the technical 4D program. The application of the 4D system during phase three was significantly lower compared to the previous phase.

2.5.4 Phase 4 – Maximizing the Benefits

In phase four, the 4D specialist enrolled again in the rhetorical 4D program convincing the CCM team members of their unrealistic assessment of the investments needed to continue the 4D modeling effort. At the end of phase four, the members of the CCM team were able to realistically assess both the costs and benefits of the 4D system, and therefore were able to translate between the rhetorical and technical 4D program in a way that allowed for efficient use of the technology. Table 2-5 summarizes the actors and the programs they enrolled in during this phase.

Enrolled Actor	Rhetorical 4D	Translation to Technical 4D	Used Enrollment Devices
4D Specialist & Project Manager C	"50% of the 3D model represents the existing conditions of the project which will not change. Thus only 35% instead of 70% will need to be remodeled." "Benefits have already been realized using the 4D	Development and documentation of working processes for generating 3D models and applying the 4D system	A memorandum with data about the 3D modeling effort so far An estimate of additional costs if the project continue to use the 4D system
Project Team	"We will use the 4D system to visualize complicated areas of the project so that we can better understand what happens." "We will simulate and plan construction sequences with the 4D system to evaluate whether the design can be built in practice." "We will use the 4D system to communicate issues and solutions to the designer, the client, and within the CCM team."	Use of 4D system to visualize the complicated areas of the project Use of the 4D system to simulate and plan construction sequences Use of the 4D system to communicate issues	4D software. Meeting room with a fixed projector that allows to plug-in computers that run 4D software easily

Table 2-5 - Actors, Enrollments, and Translation in Phase 4

At the beginning of phase four, the 4D Specialist started to research the costs of the 4D modeling effort in detail. By doing so, he confirmed that the rhetorical program coined by Project Manager C did not reflect the project's technical reality. He prepared a number of graphs and figures that he compiled in a memorandum summarizing the 3D modeling effort and detailing its costs. In addition, he prepared a slideshow summarizing the successful applications of the 4D system from phase two. Equipped with these tools, the 4D specialist was able to convince Project Manager C that his previous opinion did not reflect the reality of the 4D system implementation. Realizing his mistake Project Manager C became a strong ally of the 4D system within this phase by enrolling in the rhetorical program. Project Manager C convinced the rest of the CCM team, and together the CCM team convinced the client to fund the revision of the 3D models to reflect the changed project design. The subway department granted the funding, the 3D modelers remodeled the changed design, and the CCM team was able to continue the effective use of 4D models on the project.

Successively, the members of the CCM team started to enroll intensively in the technical 4D program. They used the 4D system to visualize the project's complicated areas, to simulate and plan construction sequences, to evaluate whether the new design could be constructed within the tight project conditions, and to communicate their solutions to external stakeholders, such as the subway department. A number of entries in the diary of the Technology Specialist provide evidence for the significant use of the 4D system to support different decision making tasks during this phase:

3/16/05:

[Project Manager C] wanted to evaluate the deconstruction schedule of the Site …

3/30/05:

[Project Manager B] needed a 4D model that shows the construction sequence of the … [one of the] … contract …[s]…. This model should then be used to clarify the construction sequence to the estimating team of the client …

4/15/05:

[Project Director] requested a schematic site model linked to the overall packaging plan. The packaging plan was on a high level and showed only a couple of construction sequences for each bid package. I created a 3D model representing the proposed and existing subways lines schematically …

5/10/05 - Merging a new schedule

[The Scheduler] asked me to help evaluating the new …[contractor's]… schedule. I merged it with the 4D model, it worked seamlessly. Then we took a look at one of the already recognized conflicts …

Entries in the diary of the 4D Specialist from March to May 2005

In the previous phases, the CCM team had only applied the model by following some of the 4D Specialist's recommendations to use the model. In this phase, the project managers themselves generated innovative ideas for using the system. The 4D specialist simply assisted in translating these ideas into reality and no longer enrolled in the rhetorical 4D program at all. The CCM team decided that the 4D Specialist was no longer needed on the project and the phase ended with the departure of the 4D Specialist.

2.5.5 Phase 5 – Lost Knowledge

The start of this phase was characterized by – what turned out to be - an overly enthusiastic attitude of the CCM team members towards the 4D system. Team members mainly enrolled in the rhetorical program, but not the technical program. During this phase, the CCM team members lost knowledge of how to use the 4D system. The phase ended with failed attempts to apply the 4D system because the project team was no longer able to translate between the rhetorical and the technical 4D program. After these failed applications, a number of actors enrolled in the rhetorical program explaining the translation failures. Table 2-6 summarizes the actors and their enrollments.

Before the 4D Specialist left the project, he stressed the 4D system benefits and supported the opinion that the CCM team would be able to work with the 4D system without his support. He developed a number of guidelines that described processes of using the 4D system and creating schedules and 3D models that were required to use the system. He also trained an office engineer (Office Engineer) in how to use the system and diffused the belief that the Office Engineer could easily take over his duties. Nevertheless, the CCM team members started using the 4D system significantly less after the 4D Specialist had left the project. Before long, none of the members of the CCM team utilized the 4D system any longer (Figure 2-1 between July 2005 and June 2006). However, the CCM team still enrolled in the rhetorical program advertising the benefits of the system both outside and inside the team. One of the project managers (Project Manager D), for example, represented the use of the 4D system as one of the new innovations used in construction at a conference. Below is an excerpt of an email Project Manager D wrote to the Technology Manager.

I want to thank you for the suggesting to [the conference planning committee] that they consider engaging me at their most recent conference to speak about [the 4D system]. The experience was positive, exposing myself and [the company] to many prospective collaborators (as well as competitors). In my opinion, each time [the company] presents at functions such as these our value to the industry is recognized.

Email from Project Manager D, May 25, 2006 (Parentheses as in original email)

Nevertheless, the CCM team in this phase was no longer using the 4D system as it had lost its ability to translate the rhetorical to the technical 4D program. The following episode describes this well. After not using the 4D system effectively for almost a year, the CCM team decided to give a presentation to the subway department using the 4D system. According to the rhetorical program prevailing in this phase, the CCM team members thought they could easily generate the 4D model for the presentation. At this time, everybody believed that 4D system processes were in place and that the Office Engineer and the 3D modelers were knowledgeable about these processes. The 4D presentation, however, was a great failure as the CCM team was not able to support the 4D system as promised. The client threatened to stop financing the 4D effort if the CCM team could not show their ability to effectively use the 4D system. The following excerpt from an email illustrates this episode.

We had a major presentation today with the client. Once again, conversion of the [3D] model files to [the 4D system] proved to be an insurmountable challenge. The client made it very clear today, if we are unable to show the value of a 4D model by next Thursday, they will no longer provide monetary support for this effort.

Email of Project Manager D from May 25, 2006

After this episode, a number of actors started to enroll both in the technical and rhetorical 4D program. At first Project Manager D started to enroll in the rhetorical program by attempting to determine, together with the Technology Manager, why the 4D system was not working for this presentation. Both actors concluded that the used software was the problem and that the CCM team should acquire different software that according to the Technology Manager

… ***has now become the preferred software solution for 4D Modeling across the industry.***

Email of the Technology Manager from May 25, 2006

Simultaneously, the Office Engineer, the 4D Specialist, and the University Professor also enrolled in the technical program to evaluate the problems. After some research, all three actors agreed that the problem was not with the 4D software itself, but with how the 3D modeler input models into the 3D modeling application. This problem was compounded due to the lack of time allotted to the 3D modelers and the Office Engineer:

[I] think the main issue we had yesterday was that [3D modeler A] was not properly shown how to organize and convert the model, and since [3D modeler B] was out for the week [3D modeler A] didn't have someone to confer with. I believe before [the Technology Specialist] left he had prepared a guide for the modelers to follow, am I

correct … ? Yet even this would have been caught if we had more time to put everything together.

The only issues we have had strictly concerning [the 4D Software] is: 1) trying to figure out where the licenses are for the full version, and for the newest version. And 2) Its tendency to crash and loose data, a month ago I lost half a day of work when [the 4D software] froze despite frequent saving, and wednesday/thursday the file had reverted back to a previous version loosing my nights work.

Email of the Office Engineer from May 26, 2006

Despite the assessments of the Office Engineer, the University Professor, and the 4D Specialist, the CCM team decided to acquire the alternative software. The presentation with the client was successfully repeated three weeks later, and the CCM team was able to continue the 4D effort. The purchase of the new 4D software was also the beginning of phase six, which we describe in the next section.

In summary, phase five was characterized by an overly optimistic rhetorical program. The optimism of the members of the CCM team led directly to the episode described above that almost halted the 4D efforts on the project. As the CCM team members realized the discrepancy between the technical reality and the rhetorical program they became once again intimidated because they could not create the 4D models that the client required, and, at the same time felt threatened as they had to generate a model within a week. This caused the CCM team to search for solutions for regaining emotional stability with respect to the 4D system implementation. Thus, the CCM team decided to purchase new software even though the technical reality of the project suggested otherwise. This purchase did not significantly improve the technical reality on the project. Therefore, we characterize the software purchase as an enrollment into the rhetorical 4D program that reflects the intimidation of the CCM team members. In any case, in the end, this enrollment into the rhetorical program helped the CCM team members to reduce their feelings of intimidation and threat and enabled the team to start into another more successful phase of the 4D system implementation.

Enrolled Actor	Rhetorical 4D	Translation to Technical 4D	Used Enrollment Devices
4D Specialist	"There are guidelines established and documented that will enable the easy use of the 4D system." "The Office Engineer is trained in using the 4D system and can take over my duties."	Leaves the project -> N/A	none
Office Engineer and 3D Modelers	"I cannot find the guidelines on my computer."	Not able to generate a needed 4D model in time for a presentation with the client	none
Project Manager D	"[4D] is the future and the future is now." "the software has not performed, rendering the model impotent!... We have no one to assist with troubleshooting. We have been abandoned."	Not able to show 4D system to the Transportation Agency Switches to new 4D software	Software
Transportation Agency	"If you are unable to show the value of a 4D model by next week, we will no longer provide monetary support for this effort."	none	none
University Professor / 4D Specialist	"fairly certain that the issue was not one with the software"	none	none
Technology Manager	"The used software has not become the preferred software solution for 4D Modeling across the industry."	Provides licenses for different 4D software	Software

Table 2-6 - Actors, Enrollments, and Translation in Phase 5

2.5.6 Phase 6 – Stabilization

Our findings show that in phase six the CCM team was able to closely match the rhetorical and the technical 4D program (Table 2-7). The close integration enabled the team to utilize the 4D system successfully. However the use in this phase was less intensive as the one we observed during phase 4. The CCM team described the utilization of the 4D system with a rhetorical 4D program that represented the 4D system as a standard tool within the CCM team's toolkit for communicating issues to non-engineers that represented closely the system's reality during this phase.

For example, the 4D system was used during a meeting with members of the different departments of the subway agency. During this meeting, different representatives of different departments had to make sure that a proposed construction plan for a part of the project would not influence the running subway operations of their department. For example, the safety department is responsible for maintaining the safety of subway riders at all times and especially in times of ongoing construction operations in the subway stations while the Operations Department's responsibility is to ensure that sufficient trains are in operation to cope with the number of passengers. Different departments often have conflicting needs during construction activities that construction plans need to account for. Usually, all departments need several weeks to evaluate, coordinate, and decide whether a specific construction plan meets all requirements. With the help of the 4D system, the CCM team and the different representatives of the departments were able to determine whether or not one of the CCM team's construction plans met all requirements in one meeting lasting only three hours. This information input from the departments, in turn, enabled the CCM team to decide faster that the specific design for this part of the project was constructible. An interview with one of the project managers provides evidence for this huge success.

Oh yes we still use the 4D system. Last week we just had an outstanding success. We invited a number of people from [the subway department] over to review the latest schedule that we created for the [one of the subway lines]. By seeing the schedule simulated within the model, they were able to sign off on our plan within 3 hours. This process would have usually lasted 3 weeks if not longer.

Interview with Project Manager A from May 21, 2007

Enrolled Actor	Rhetorical 4D	Translation to Technical 4D	Used Enrollment Devices
Project Manager A	"We used the tool successfully in three occasions to coordinate and understand the project and to communicate complex issues to the client organization."	Use of the 4D system to understand the project and to communicate issues to the subway department	New 4D software
Project Director	"helped people to deal with people" "early waste of money, need to access the risk-reward of modeling"	none	none
Subway Department	"convinced of the benefits of the 4D system"	none	none

Table 2-7 - Actors, Enrollments, and Translation in Phase 6

Data from another interview with the CCM team's project director (Project Director) show that during this phase the members of the CCM team enrolled in the rhetorical 4D program in a way that realistically reflected the technical 4D program.

I mean 4D is useful for construction planning and we have used it within the last couple of months a number of times. At the beginning we were overenthusiastic and did not know how to use 4D right. We spent a lot of money on modeling things we really did not need to see in the model. But in the end, 4D is very helpful.

Interview with the Project Director from May 21, 2007

During our four visits in this phase we conducted several interviews with different members of the CCM team during which the viewpoints of the actors with respect to the 4D system did not change. These interviews show that the CCM team did not use the 4D system as frequently in this phase as the team did in phase 4 (Figure 2-1). The accounts of the CCM team members were positive throughout. As we could not find any more variations within the statements of the different actors during this phase, we will close our narrative about the implementation of the 4D system on the project. In the next section, we ground our narrative in existing theory that provides a general model to explain the findings from this case.

2.6 Theoretical Grounding of the Findings

Our observations show that the project managers on the project were the main drivers of the 4D system implementation and that the implementation therefore was driven in a grassroots fashion by project team members that work at the construction firm's operational level. This section develops a number of theoretically grounded explanations for the grassroots implementation processes that we observed on the project. To match the observations from the case, a grassroots theory needs to describe two distinct constructs: how project team members make sense during a decision support system implementation, and how this sense-making process is influenced by the informal power structure that exists within project teams. This section, therefore, first uses the ANT concept of black-boxing to explain how the members of a project team make sense of a decision support system and use it accordingly. The section then, explains the informal power structure that exists within project teams and how this power structure influences the sense-making process.

2.6.1 Actor-Network Theory: Black-Boxing and Un-Black-Boxing

Sociologists initially developed ANT to describe the work of engineers and scientists in their laboratories or offices during the development of new products (Latour 1987: 2). Black-boxing is one of the important concepts they use for their descriptions. Black-boxing can be described as follows: to create a new product engineers first evaluate a vast number of facts and details that influence the product's final character. These facts and details are not only of a technical nature, but also of a managerial and application related nature that describe how the product can be applied in practice. Furthermore the features are not of a fixed nature, but can be changed by actors. To successfully develop a product, the engineers also need to enroll other actors to support the development of the product, such as financiers, other engineers, public agencies, or potential buyers of the new product. To mobilize these other resources, engineers simplify the product under development to enable these actors to grasp the basic ideas behind the product without the need to understand all details. For example, during the initial development of the 4D system prior to the implementation on the project actors black-boxed the 4D system as an idea that researchers first developed in an industrial R&D lab. As a next step during the development process, researchers at the university black-boxed the 4D system in a way that allowed software companies to enroll in the idea of supporting construction project management with the 4D system (McKinney 1996; Koo & Fischer 2000). These software companies then, in another black-boxing effort, implemented software that made 4D systems readily usable in practical settings. The story of this paper, however, shows another effect of black boxing. Our findings show that the project managers on the project were required to un-black-box[1] the 4D system that was shipped by the software company to make it useful on the project. Thus, the mechanism of black-boxing of ANT is not only a good concept to describe the black-boxing processes that need to occur during the development of a product, but also to describe the un-black-boxing processes that need to occur during grassroots implementations of decision support systems.

Our findings show that actors frequently black-boxed and un-black-boxed the 4D system in the local project context. After the first phase, the Technology Manager and the University Professor black-boxed the 4D system. This black-boxing enabled the project team to initially enroll in the idea of 4D-supported project management and encouraged them to decide to implement a 4D system on the project. To be able to use the 4D system in the local project context, the CCM team then needed to un-black-box the 4D system into applicable managerial and technical machines that could efficiently support the decision making tasks of the team. These un-black-boxing processes were interrupted by additional black-boxing processes whenever members of the CCM team enrolled other actors in the 4D system effort. For example, in phase three, Project Manager C black-boxed the system, hiding the fact that the 4D technology had already been used successfully in phase two, and stressing the system's costs. These black-boxing efforts enabled Project Manager C to enroll the other team members in his anti-4D-program. Another example of further black-boxing can be found in phase five where the 4D Specialist enrolled in the rhetorical program stressing that the 4D system can be applied seamlessly.

As mentioned earlier, our findings show that the members of the CCM team needed to un-black-box the 4D system to utilize it in their local conditions. Our findings furthermore show that CCM team members had to un-black-box the 4D system by themselves by interacting with it to successfully use the system. This is especially evident in the implementation of phases two, four, and six.

As we describe above, our findings also show that the actors at the operational level of the project team had to drive the technology implementation to make it useful on the project. The influence of actors that were not CCM team members during un-black-boxing was limited. These actors were reduced to the role of fashion setters that tried to influence the CCM team members from the outside without any formal power over the implementation decisions of the members of the CCM team (Abrahamson; 1991). Our findings show that the

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[1] While Callon and Latour (1981:285) use the term of a leaking black boxes, we decided to use the term "un-black-boxing" to show the process by which actors enroll into a program to understand the contents of a black-box. Our observations show that black-boxes do not passively "leak", but that actors need to open parts of the black-box intentionally.

fashion setters had only limited power to enroll in the un-black-boxing process on the project. We summarize these theoretical considerations in the following grounded explanations:

Grounded Explanation 1:

To be able to apply the 4D system on the project, the member's of the CCM team had to un-black-box the features of the 4D system.

Grounded Explanation 2:

Fashion setters had only limited influence over the un-black-boxing process necessary for making the 4D system applicable on the project.

With the limited influence of actors that were not members of the CCM team on the un-black-boxing process, grounded explanations one and two suggest that the implementation of the 4D system on the project was only successful at times when the implementation was driven by the CCM members themselves in a bottom-up grassroots process. Our findings show that the CCM team members together made sense of the 4D system during un-black-boxing. The next section, therefore grounds our findings about how the CCM team members made sense of the 4D implementation while implementing the 4D system using social sense-making theory.

2.6.2 Un-Black-Boxing as Mutual Structuration of Social Systems and Technology

Structuration theory (Giddens 1986) describes the CCM team's sense-making process during un-black-boxing well. In contrast to Orlikowski's (1992) model of the duality of technology, which posits that technology is both physically and socially constructed by the actors within a local system, we apply the concept of the duality of structuration theory to show that physical features of the technology influences social structures and that social structures at the same time influence the configuration of the physical features of the technology. In this way, our model resembles the structuration process described by Barley (1986), but apply it to the more complex area of decision support system implementation by project teams.

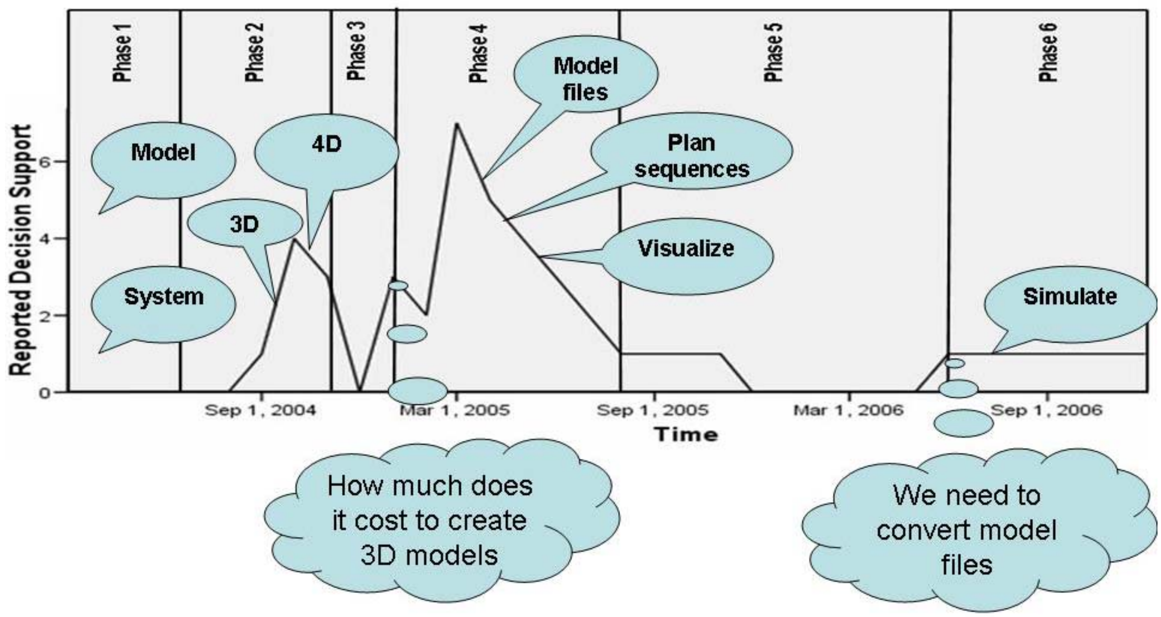

Figure 2-3 - Structuration of the language used by the CCM team – In phases of effective utilization project team members learned new language that they could use to make sense about the system in later stages (represented in sense-making clouds)

Structuration processes were especially evident in the ways the CCM team used language to describe the 4D system. Figure 2-3 summarizes the CCM team members' language from the statements of the previous section. By doing so, Figure 2-3 reveals the CCM team's structuration of language with respect to the 4D system. Over time, the members built a common language for talking about the 4D system. This common language defined, in turn, what the different members knew about the 4D system, and accordingly how they interacted with the 4D system. For example, the project team members were able to start evaluating the costs of 3D modeling in phase three and four after they integrated the concept of "3D models" that was required as an input to the 4D system into their common language. Another example for the language structuration process is the use of the term "model files", which was integrated into the common stock of knowledge during phase three, and was used to understand the technical problems in phase five. These processes are similar to the process of the social construction of reality described by Berger and Luckmann (1990). By interacting with each other the members of the CCM team mutually defined a common spirit[1]

[1] The term spirit was developed by DeSanctis and Poole (1994). DeSanctis and Poole (1994) compare the spirit of a technology with the spirit of a legal law. "Government institutions provide systems of law that can be described both in their terms of letters, which detail specific rules and resources for

for the 4D system that defines the technical, managerial, and application related feures of the technology with respect to potential benefits the technology offers and how to best implement the technology considering the local project context (Majchrazak et al. 2000; DeSanctis & Poole 1994). Thus the term spirit is a theoretical conceptualization of the rhetorical program we describe in the case narrative above. This spirit in turn enabled the members of the CCM team to make sense of the 4D system within their local context and thus influenced how they used the 4D system.

Grounded Explanation 3:

How the CCM team members used the 4D system was influenced by the CCM team's socially constructed spirit.

Additionally, the members of the CCM team updated the commonly used language and therefore the spirit of the 4D system by directly interacting with the technology. The CCM team, for example, integrated the terms “3D” and “4D” into their common language after their first applications of the 4D system in phase two. While evaluating the cost of the value engineering changes, the CCM team members understood the concept of “3D model files” which they subsequently integrated into their common language. Furthermore, after the extensive use of the 4D systems during phase four, the CCM team integrated the terms “visualize”, “communicate”, and “plan sequence” into their common language. By integrating these terms into their common language, the CCM team also changed the spirit of the 4D system on the project, as the members of the team were now able to communicate their use of the system.

Grounded Explanation 4:

While using the 4D system the CCM team updated their commonly used language about the 4D system and, therefore, the spirit of the 4D system.

Additionally, our findings shed light on the individual appraisal process. The decision of individual CCM team members to use the 4D system was not only influenced by the CCM team members' direct interactions, with the 4D system, but also by the 4D system's spirit. Again, ANT and structuration theory help to explain our findings. In lieu of structuration theory

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action, and their spirit, which is the consensus about values and goals that are appropriate in society (DeSanctis & Poole 1994:127)”. We use this term similarly defining the spirit as the subjective characteristics of the 4D system as they are jointly perceived by the members of the project team. With this definition we are able to contrast the spirit as macro characteristics of the 4D system as perceived jointly by the project team. The spirit can correspond to the technical reality that defines the objective characteristics of the 4D system more or less closely.

(Giddens 1986:25), the technology's spirit as represented by the rhetoric that the CCM team members jointly used both enabled and constrained their opportunities to use the 4D system. Our evidence shows that when the spirit did not closely represent a realistic way of using the 4D system on the project, the spirit of the technology constrained how the members of the project team applied the technology. A large effort was required to translate between the socially constructed spirit and the objective technical 4D system. To make the 4D system useable on the project the members of the project team needed to invest large amounts of translation energy to narrow the gap between the spirit and the technical reality. This in turn led to the perception that the 4D system did not offer the potential to improve decision making tasks and of little control of implementing the 4D system. Accordingly, if the gap between the spirit and the technical reality was large, the members of the CCM team did not widely apply the 4D system to support decision making. This constraining characteristic of the spirit is especially evident in the unsuccessful phases one, three, and five of the implementation effort.

Grounded Explanation 5:

When the gap between the spirit and the technical 4D program was large on the project, the gap constrained how CCM team members were able to apply the 4D system.

On the other hand, when the spirit was close to the technical reality of the 4D system, the spirit had an enabling character. CCM team members required little energy to translate between the rhetorical and the technical 4D program. Accordingly, in the successful phases two, four, and, six CCM team members started to feel that the 4D system offered an opportunity for improving decision making. Furthermore, the members felt control over the implementation process within their local environment. Accordingly, they started utilizing the 4D system to support their decision making tasks.

Grounded Explanation 6:

In phases when the gap between the rhetorical and the technical 4D program was small the CCM team members were able to un-black-box the 4D system and use it effectively to support their decision making tasks.

The findings of grounded explanation five and six are similar to the findings of other researchers. For example, Zbaracki (1998) found that a large gap between how people talked about a technology and how the technology was used in reality affected the level of utilization within the context of Total Quality Management program implementations. Similarly, Macri et al. (1999) found that the difference between professed and performed ideas with respect to the implementation of an information system in a small firm influenced the amount of utilization.

2.6.3 Technology Implementation in Flat Hierarchies

The previous section explains how individuals at the operational level of an organization make sense about and decide how to use a new technology. Additionally, a grassroots model of decision support implementation by project teams also needs to explain the power structures within project teams to shed light on how much individual project team members can influence the implementation process. Our findings show that different members of the project team were able to influence the local spirit of the new technology differently.

Throughout the implementation of the 4D system on the project it is evident that formal authority was not a major factor in influencing the spirit of the 4D system. The formal leader of the CCM team was the Project Director. However, our observations show that the Project Director was not a driver of the technology implementation. Instead, the project managers of the CCM team that were responsible for making decisions at the operational level drove the implementation. Furthermore, our findings show that the subway department as the founder of the project's 4D effort lacked the power to coercively influence how the CCM team used the system. Additionally, in contrast to the diffusion of innovation theory that stresses the importance of change agents (Rogers 2003:Chapter 9), the Technology Specialist, as a change agent, could not influence the spirit significantly. Only when project managers supported the Technology Specialist was he successfully in shaping the 4D system's spirit. This is, for example, evident in phase 3 when the experienced Project Manager C was able to integrate his wrong believe about the costs of the system in the spirit.

There are two causes that can explain our findings. First, the hierarchy of the CCM team was very flat. Second, most knowledge that team members require to produce a one-of-a-kind product is not explicitly available but resides only tacitly within the minds of the engineers (Kreiner 1995). Therefore, even if formal authority positions are established within the team, such as the project director's position in the CCM team, there is rarely an opportunity for the incumbents of these positions to control their subordinates on the project. Additionally, the corporate management's formal authority is also limited as there is little direct contact between project team members and corporate management (Gann & Salter 2000). In organizations with few formal authority structures, organizational members will build up power structures that rely on control by peer review (Foucault 1979; Barker 1993). In such organizations, power is usually attributed to the members that are perceived to be most competent at solving the problems at hand (Cicourel 1990; Barker 1993). Thus, project team members that are perceived by their peers as the persons that are able to solve the project's critical problems will have most power (Pfeffer 1992: 154). As the tacit knowledge that is required to solve the complex tasks on projects can only be acquired by actively pursuing problems, experience is an important factor to acquire such tacit knowledge (Polanyi 1996; Cook & Brown 1999).

In accordance with the empirical and theoretical research presented above, our findings show that it is most likely that the competency individuals attribute to their peers is strongly dependent on the previous experience that those peers bring with them to the project team. Only when experienced project managers enrolled positively in the technical 4D program in phase two and especially in phase four and six the 4D system was utilized. On the other hand, phase three shows that utilization of the 4D system declined as an experienced project manager enrolled negatively into the rhetorical 4D program. In most of the phases, the 4D Specialist, or the Office Engineer, as inexperienced members of the team with respect to construction management tasks were not, on their own, able to shape the rhetorical or the technical 4D program to cause a widespread utilization of the 4D system.

Grounded Explanation 7:

The experienced members of the CCM team were the drivers of the 4D system use on the project.

Furthermore, our findings show that, due to the always changing environments of projects it is not easy for individual members of the team to build up a stable perception of the experience of their peers. Therefore, contrary to Barker's (1993) findings about self-organized teams working in factories, it is unlikely that a stable concertive power structure within project teams will ever be established. Project team members will perceive different peers to be more competent at different times according to the nature of the tasks that need to be solved. Again, this proposition is well supported by our findings, as different project managers at different times during the project are able to enroll differently within the rhetorical and technical 4D program. These findings reinforce existing organizational research that stresses the idea that different members will be opinion leaders of teams at different times (Fruchter et al. 2007; Majchrazak et al. 2000).

Grounded Explanation 8:

Different CCM team members were able to shape the rhetorical 4D program differently according to the experience the other CCM team members attributed to them.

Summarizing, the grounded theory we developed in this section concerning the power structures within a project team adds to the previously explained theory about how the technology's spirit is mutually structurated by the members of the team. Together, both theories can explain how a decision support system is implemented by the members that work at the operational level of a project team.

2.7 Limitations and Boundary Conditions

This section discusses some of the limitations and boundary conditions of our findings. In general, a study that is based upon a single case opens discussions about the generalizability of the findings. Therefore, throughout this paper, we can and do not claim that our observations are applicable for the implementation of decision support systems on other projects. However, the insights of the case complement other single case studies in the area of technology implementation (Orlikowski 1992; Orlikowski,; 1996; Mazrachjzak et al. 2000) due to its extremity with respect to the complexity of the decision support system and of the project team we observed. Thus, our findings offer a fresh viewpoint on the implementation of complex decision support systems in complex organizational settings that other theories about the implementation of technologies cannot offer.

We showed that the implementation of the 4D system on the project was influenced by a number of additional constraints that other types of technology systems do not possess. Specifically, the use of the 4D system could not be mandated by upper management actors, the success of the 4D system implementation depended on the level of integration of the technology by the social organization, and the 4D system consisted of a large number of technical features that the CCM team needed to appropriate to local task requirements during implementation. Due to these extreme characteristics of the 4D system our findings offer new insights to the field of technology implementation. However, we expect that our findings might not explain implementations of other technologies. For example, the grounded explanations we derived in this paper might have only limited applicability for the implementation of technologies that store data for accountability reasons because upper management can often easily mandate the use of accountability systems, or for systems that automate construction management tasks because project teams, in general, do not need to configure the features of automation systems to their working tasks. Another boundary condition from a technological standpoint is our assessment of successful applications of the 4D system on the project. Throughout this paper, we analyzed the CCM team members' perspective of effective use, ignoring opportunities of 4D system application that might represent success for other groups of actors at different organizational levels. For example, it is quite possible that upper management agencies have a large interest in implementing 4D systems on a number of their company's projects to be able to show clients how advanced the company is. In such cases, upper management may have only limited interest in the efficiency of the 4D system to support decisions of the company's employees that work at the operational level, especially on the first few pilot projects.

Furthermore, the findings we presented in this paper were derived from observations from a construction project management team operating in the United States of America. Our findings might, therefore, have limited applicability for other project teams that implement decision support systems in other parts of the world. These project teams might have different internal power structures with respect to the formal hierarchy and experience of its members based on differences in values in areas like power distance and uncertainty avoidance (Gannon 2001; Schneider 1990; Hofstede 2001).

2.8 Conclusion

Our description of the implementation of the 4D system by the CCM team and our grounded theory of grassroots technology implementations illustrates and explains the implementation of decision support systems by organizations characterized by temporary, flat hierarchies. We show that the decision support system was utilized more in phases in which project team members' perceptions about the system closely matched the opportunities the system offered in reality. Our observations also show that more experienced members of the project team were able to influence how project team members talked about the technology and how project team members used the technology during different phases of the project. In this way, the paper shows how individuals working at the operational level of a project team implemented a new technology without much influence of individuals that work at higher hierarchical levels of the project team's corporate organization. The paper's findings help project team members to understand decision support system implementation processes better. We show that project managers might actively need to enroll in the decision support system implementation to make it successful. An implementation with a passive involvement of the project managers with technology managers configuring and implementing the system for the project team might not work well.

Additionally, the study shows that decision support system implementations by project teams might not always proceed as continuously as depicted by structural deterministic or evolutionary implementation models (see Rogers 2003 for a good overview of the implementation literature). Thus, the grounded explanations we developed within this paper can help technology managers of project-based companies to understand discontinuous implementations of complex decision support systems better. In summary, it is important for technology managers to realize that their power during the implementation of decision support systems by project teams might be limited to that of fashion setters that can only drive the implementation to some extent without the help of project managers.

With these insights, this case study sheds new light on the problems that project-based industries face with the implementation of technologies. The case study and the initial concepts that this paper develops help project managers and technology managers to understand bottom-up emergent grassroots processes during decision support system implementations by project teams better. Furthermore, the paper's findings present a first starting point for further theoretical and empirical work that is geared toward a better understanding of such grassroots processes during the implementation of decision support systems by project teams and by other organizations.

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3 Sense-making during the Implementation of Decision Support Systems in Project Teams: Understanding Grassroots IT Implementations

3.1 Abstract

Based on empirical observations reported in chapter 2 this paper deduces a theoretical grassroots model of decision support system implementations from an in-depth literature review. Reviewing relevant project management and decision support system implementation theories, the paper first develops the theoretical argument that project team members at the operational level need to drive the implementation effort without much support from outside agencies in a grassroots process. Based on this argument we show that prevailing micro-sociological technology implementation theories do not sufficiently explain such grassroots implementation situations. To overcome the shortcoming of these existing theories, the paper then develops a theoretical model by applying social sense-making and socialization theories to the field of decision support systems in project teams to develop a grassroots model of decision support system implementation by project teams. The model posits that the gap between the subjective spirit of the project team and the objective technical reality of the project team's environment influences the perceived feelings of control and opportunity on the part of individual project team members. The perceived amount of opportunity and control of the individual project team members, in turn, influences whether and how they start using the system to support the team's decision making tasks. We close the paper by discussing a number of management recommendations that directly follow from the deduced grassroots model addressing technology managers of project-based companies. In particular, we suggest that such managers work closely with project teams during the implementation phase, instead of trying to push technologies down through the hierarchical structures of their companies.

3.2 Introduction

Projects are temporary forms of organization in which control about how to define the requirements of output and how output is produced remains with the specialist at the operative level. This, in turn, enables specialists to work freely on tasks that require a high amount of creativity and tacit knowledge to be solved (Kreiner 1995) as constant reporting to, and control of decisions by, upper management agencies is no longer required. In recent years, many companies have started to restructure their internal organization from a hierarchically organized structure to the use of more and more project teams whose members are largely detached from the formal hierarchy of the company (Cohen & Bailey 1997; Gann & Salter 2000).

To support such creative project work individuals can benefit significantly from utilizing decision support systems (Gann & Salter 2000). Such decision support systems are systems of hardware, software, and processes that are designed to support the decisions of project team members during unstructured or semi-structured decision making tasks. With their focus on supporting decisions such systems are different from management information systems that store and process information to create scheduled reports, or from electronic data processing technologies that completely automate decision tasks without the need for human intervention (Bidgoli 2003; 1997). Contrary to the implementation of management information systems and data processing technologies, the implementation of decision support systems requires a more active involvement of the users (Bidgoli 1997: 13). The need for such an active involvement might explain why managing decision support system implementations by project teams remains a problematic area for research and practice (Adriaanse 2007; Taylor & Levitt 2007).

Most of the existing research focuses on the implementation of information systems in relatively stable and hierarchical organizations and so it cannot be compared with the more dynamic settings existing in project teams. In particular, these models usually explicitly or implicityly assume that (1) upper management can mandate the use of the technology (Barley 1989; Orlikowski 1996); (2) organizational members are able to implement the technology successfully on their own, without a wide acceptance and level of integration within the organization (Davis 1989; Goodhue 1995); (3) organizational members are granted the time to learn the technology slowly (Tyre & Orlikowski 1996; Orlikowski 1996); and (4) a fixed political structure exists that influences the implementation (Markus 1983).

Contrary to the implementations of technologies in non-project based organizations, Brady and Davies (2004) propose that, before project-based companies diffuse a new strategy on different projects, single projects should explore the new strategy first. To improve the understanding of such implementations on single projects, this paper explains the social sense-making process during the implementation of a decision support system on a single project and how the members of the project team use the decision support system according to the outcomes of this sense-making process. Specifically, the paper deductively develops a model of grassroots decision support system implementations by applying organizational sense-making (Weick 1995) and sociology of socialization theory (Berger & Luckmann 1990) to the field of technology implementation. The model uses structuration theory (Giddens 1986) to consider the dual influence of how the project team socially constructs the reality of the decision support system and how the project team is influenced at the same time by the objective technical reality of the system. In this way the model can explain the two sense-making processes described by Weick (1995:134) of how project team members make sense of a decision support system by directly interacting with the technology and at the same time by sharing personal beliefs with other project team members. The model gives insights about how individuals and teams make choices about how to use decision support systems. Furthermore, the model gives insights about how individuals and project teams change their work processes and the technology concurrently and iteratively according to how project team members make sense about the decision support system. In addition to complementing organizational choice and change theories, the model also gives valuable insights about how technology managers of project-based companies can support projects with managing such grassroots implementations.

The paper starts with an overview of the project management and decision support systems literature and discusses in detail why existing micro-sociological models have little descriptive power to explain the implementation processes of decision support systems by project teams. Then we develop the model by reviewing the existing micro-sociological technology implementation literature and integrating the different theories into the model by using a number of propositions. In a next step, we position the model within the broader field of organizational science and discuss a number of theoretical implications. The paper concludes with practical recommendations derived from the model for technology managers that plan to implement decision support systems with project teams.

3.3 Decision Support Systems and Project Teams

Companies establish temporary project teams to cope with the highly complex circumstances during the production of one-of-a-kind or highly customizable products. Such project teams get constantly changing feedback from their environment; most knowledge to accomplish project tasks is possessed tacitly by the individuals of the project team and often requires high creativity to be applied; and the client’s requirements with respect to the product are often ill-defined and unstable (Kreiner 1995). Internally each member of the project team usually works on a relatively autonomous task. However, at the same time, each member needs to consider informational input from other team members as tasks in project environments are highly reciprocal (Gann & Salter 2000; Thompson 1967). Thus strong internal collaboration between the members is needed. Additionally, project teams need to communicate extensively with the outside environment.

To manage the complexities during the production of one-of-a-kind products, project teams are largely detached from the formal hierarchy of the company (Cohen & Bailey 1997). This enables the project team members to make their decisions at the operational level without deferring decisions by passing exceptions to supervisors or upper managers in a chain of command (Galbraith 1974). Therefore, project teams are themselves characterized by a flat internal power structure that mainly operates with concertive methods of control (Foucault 1979; Barker 1993) by which the members of the project team control their peers directly without the need of hierarchical supervision.

Project team members usually come from various technical backgrounds to cope with the different task requirements during the production of their unique product. Though project teams are detached from the formal hierarchy, project teams need to interact with their company's upper management to enable the overall cooperate resource planning. Furthermore, to reap scale economies, corporations establish central organizational units to support project teams with their resource allocation, such as a centralized IT department to support project teams with required technological resources.

Work on projects is characterized by unstructured or semi-structured decision making tasks that require creativity, tacit knowledge, and joint information input from various parties (Cohen & Bailey 1997). Individuals within project teams can benefit greatly from decision support systems that are specifically developed to support such unstructured or semi-structured decision making tasks. In particular, decision support systems support project teams with information processing and visualization features (Zigurs & Buckland 1998) and with capturing and sharing of knowledge (Majchrzak et al. 2000). With their capability to clearly visualize complicated data, decision support systems also improve the communication of problems, starting points, and solutions within the project team and to external stakeholders. Additionally, group decision support systems can reduce communication barriers between team members by providing a clear focus for group discussions (Bidgoli 1997:17). In general, if implemented well, decision support systems promise to improve the productivity of the team (Nunamaker et al. 1989, Watson et al. 1988, Dennis et al. 1988) by helping to structure its internal and external processes with respect to planning, problem solving and choice making (Dennis et al. 1988; DeSanctis & Gallupe 1987; Huber 1984).

As decision support systems are loosely coupled systems of hardware, software, and user processes (Bidgoli 1997:13) they usually offer a bundle of features that project team members can arrange in many different ways during the implementation (Gutek et al. 1984; DeSanctis & Poole 1994; Rice & Rogers 1980). How to use a decision support system is usually not clearly defined and different uses can lead to the same solution or the same use can lead to different solutions (Leonard-Barton 1988). Thus, project team members need to constantly appropriate features of the technology to fit the context of the local tasks at hand (Rice & Rogers 1980; Rogers 2003:181; Ives & Olson 1984; Clark 1987; Leonard-Barton 1988; Poole & DeSanctis 1990; Sokol 1994). Furthermore, even if the project team members have the system available for use, they can rely on the old ways of solving the task or they can use alternative ways to apply the system that were not anticipated by the developers of the technology. Upper management cannot distinguish how or whether a project team member made a decision with the system (Clark 1987; Sokol 1994). Thus, the upper management of the project team's company cannot mandate or control the use of decision support systems.

Because of these decision support system and project team characteristics there are a number of intertwined factors that are rarely considered by the micro-sociological research on technology implementation. First, the success of a decision support system is dependent on the level of integration of the system in the project team. Most of the team members have to decide on common ways to use a single decision support system, so that the decision support system can support decisions of individual project team members effectively. Implementation models that solely focus on how individuals decide to use a technology (Davis 1989; Davis et al. 1989; Goodhue 1995; Goodhue & Thompson 1995; Beaudry & Pinsonneault 2005; Dishaw & Strong, 1999) do not explain the individual team members' mutual influence on each other. Second, as described earlier, the use of decision support systems is voluntary; leaders from within or from outside the team cannot mandate its use. A consensus has to be reached among a majority of the project team members on how to utilize the system so that it can be used effectively. Therefore, implementation models that assume that senior managers within the organization mandate a technology's use by subordinate organizational members within a relatively stable organization as the managers in, for example, Barley's (1986) or Orlikowski's (1996) studies do, are not applicable. Third, project teams are formed from project to project and thus there is little initial consensus on what technologies to utilize during the project. Usually, by the time consensus is found, the project is already well underway. If a project team wants to implement a decision support system efficiently, it has to make a quick and early decision about the implementation. Furthermore, project teams are "learning disabled". As project teams are abolished and reformed with new members from project to project, knowledge about the benefits and about the implementation of the decision support system is lost. Therefore, evolutionary management models that explain that organizations will find ways to efficiently utilize technologies over time (Tyre & Orlikowski 1994; Tyre & Orlikowski 1996) do not explain the situation in project teams well.

Furthermore, routine based learning theories that propose that the more a decision support system disrupts existing routines the more individuals will resist to use it (Levitt & March 1988) are often not applicable as project teams will not be able to establish strong routines in the short time they work together. Fourth, as users can arrange the decision support system's features in different ways, different possibilities to integrate the use of the system in existing routines of the project team exist. It is not easily possible to determine a priori whether a decision support system will fit into the existing routines or not before project team members have started using it for some time. Therefore, managers can hardly use theories that propose that users will reject a decision support system if it does not fit the decision making tasks of the project team well (Levitt & March 1988; Dishaw & Strong 1999; Goodhue 1995; Goodhue & Thompson 1995; Zigurs & Buckland 1998) to predict a priori to what extent a project team will use a system. Finally, models that assume that a strong political power structure within an organization influences the implementation of technologies by individuals (e.g. Markus 1983) do not consider project team settings with flat and concertive power structures.

Due to this flat power structure in project teams and the difficulty for managers to mandate the use of a decision support system, the project team members themselves largely decide how they utilize the decision support system within their local context. This decision is to a great extent independent from upper management considerations. Such dynamics can be explained by the grassroots implementation framework that we deduce in the following section from the organizational science and information management science literatures.

3.4 A Grassroots Model of Decision Support System Implementation

Most models of the lifecycle of technologies assume that a technology is first invented, than developed and finally implemented within specific organizations (Rogers 2003: 138). Only after implementation can the members of the social system start utilizing the technology. However, after an organization has decided to implement a decision support system accounting for economic or institutional forces, this further distinction between phases is not necessarily valid, as the boundary between the phases of implementation and use is at best blurry (Latour 1987: 107). Often technologies are reinvented and redeveloped during implementation as an organization appropriates an invention for purposes that the inventor did not initially intend (Rice & Rogers 1980; Rogers 2003:181; Ives & Olson 1984; Clark 1987; Leonard-Barton 1988; Poole & DeSanctis 1990; Sokol, 1994). Accordingly, we assume that an implementation process is the ongoing process of project team members purposely appropriating a decision support system to local work tasks throughout the use of the system within the local environment, while they at the same time appropriating their social structures, routines, and work tasks to the use of the decision support system. As opposed to overall use, we define effective use according to two criteria. First, the decision support system supports the project team members in making decisions faster. Second, the system can support the team members in making decisions that generate higher quality solutions.

It is important to understand how individuals make sense of a new technology during the implementation as a starting point for the development of a grassroots theory that can explain such an implementation process,. Sense-making is the process that project team members use to interpret how the implementation of a decision support system affects the work processes in their local environment. According to these value orientations the members then develop causal explanations of how they expect the decision support system to influence the existing work processes (Dutton & Dukerich 1991; Elsbach 1996). Contrary to research about organizational sense-making (Elsbach 1996) that considers sense-making processes of organizational groups, we see sense-making as an individual process in the context of this paper. Sociologists usually describe such sense-making processes of individuals using one of two theoretical models. The first model, commonly termed the social construction of reality, assumes that individuals within social systems mutually build a common stock of knowledge by interacting with each other (Berger & Luckmann 1990). This common stock of knowledge, in turn, influences how individuals make sense of the decision support system within the local environment and social system (e.g. Majchrazak et al. 2000; DeSanctis & Poole 1994). The second model, commonly termed structural determination, assumes that existing social norms, values and environmental factors constrain the conduct of individuals (Parsons 1968). This theory assumes that existing structures of the technology, the local environment, and the social system determine how individuals make sense of a technology (Davis 1989; Davis et al. 1989; Goodhue & Thompson 1995; Beaudry & Pinsonneault 2005). Our literature review shows that technology implementation research has used both of these theories to explain how individuals make sense of a technology and accordingly utilize it within their local conditions.

Structuration theory proposes that individuals simultaneously use both social construction of reality and structural determination processes during sense-making, and that both of these processes constantly influence each other (Giddens 1986; Orlikowski 1996; Orlikowski 2000; Barley 1986). On one hand, the sense-making process of members of the project team about a decision support system is shaped by the spirit that describes what is commonly known by the project team (DeSanctis & Poole 1994; Elsbach 1996). This spirit is manifested and influenced by rhetoric as members of the team interact with each other. On the other hand, technological reality shapes individual sense-making processes as project team members constantly interact with the decision support system within the specific environment and social structures of the project. By communicating the causal explanations that characterize the decision support system that have been developed during the sense-making process the individuals then influence the spirit in the next use cycle. We formalize the structuration perspective in a guiding proposition for the theoretical framework we develop in this paper.

Guiding Proposition: The sense-making process during the implementation of a decision support system by project team members is characterized by the mutual social interaction of the project team members with each other and by the interaction of individual members of the project team with the technology.

The rest of this section develops a number of propositions that integrate existing technology implementation theories into an implementation model for decision support systems by project teams. Figure 3-1 shows an overview of the framework. Furthermore, we summarize the most important definitions that we use throughout this paper in Table 3-1. The model explains in detail how a project team jointly develops a subjective spirit that combines individual decision making outcomes to legitimate the decision support system within the project team (DeSanctis & Poole 1994; Elsbach 1996). The project team develops this spirit by updating its common stock of knowledge with the individual knowledge of the team members by frequently interacting with each other. Agents from outside the project team that we call fashion-setters mainly influence the individual sense-making processes and experienced project team members are more likely to influence the development of the spirit than inexperienced members. Furthermore, we propose that there exists a gap between the subjective spirit of the technology and the objective technical reality that represents the decision support system's potential to support the project team's decision making. This gap influences how individual project team members make sense about the control they have over how they use the decision support system and what opportunities the use of the system offers them. This sense-making process in turn influences how members of the project team use the system. Finally, the use of the decision support system by the project team members influences their individual knowledge about the system in their local environment and social system.

We start deducing the grassroots model by synthesizing literature about how project team members use the outcomes of their individual sense-making processes to mutually define the spirit of the technology. Then we review the literature about individual sense-making processes and deductively explain how these processes influence how individuals utilize a decision support system. Finally, we will explain how system use influences individual sense-making processes and, therefore, our model shows grassroots implementations as an ongoing and process.

Implementation	The mutual process of adapting the technical features of the decision support system to the work processes of the project team and appropriating the work processes of the project team to the technical features of the decision support system (Majchrazak et al. 2000; Leonard-Barton 1988).
Sense-Making	Individual interpretation of how a technology is able to influence existing work processes and the subsequent development of value orientations that describe the characteristics of the technology within the local organization (Dutton & Dukerich 1991; Elsbach 1996).
Structuration	Duality of the influence of system use on the sense-making process and the influence of the sense-making process on system use (Giddens 1986).
Spirit	The subjective characteristics of the decision support system as they are jointly perceived by the members of the project team (Majchrazak et al. 2000; DeSanctis & Poole 1994).
Technical Reality	The existing objective potential of the system to support the project team's decision making tasks.

Table 3-1 - Definitions used throughout the paper

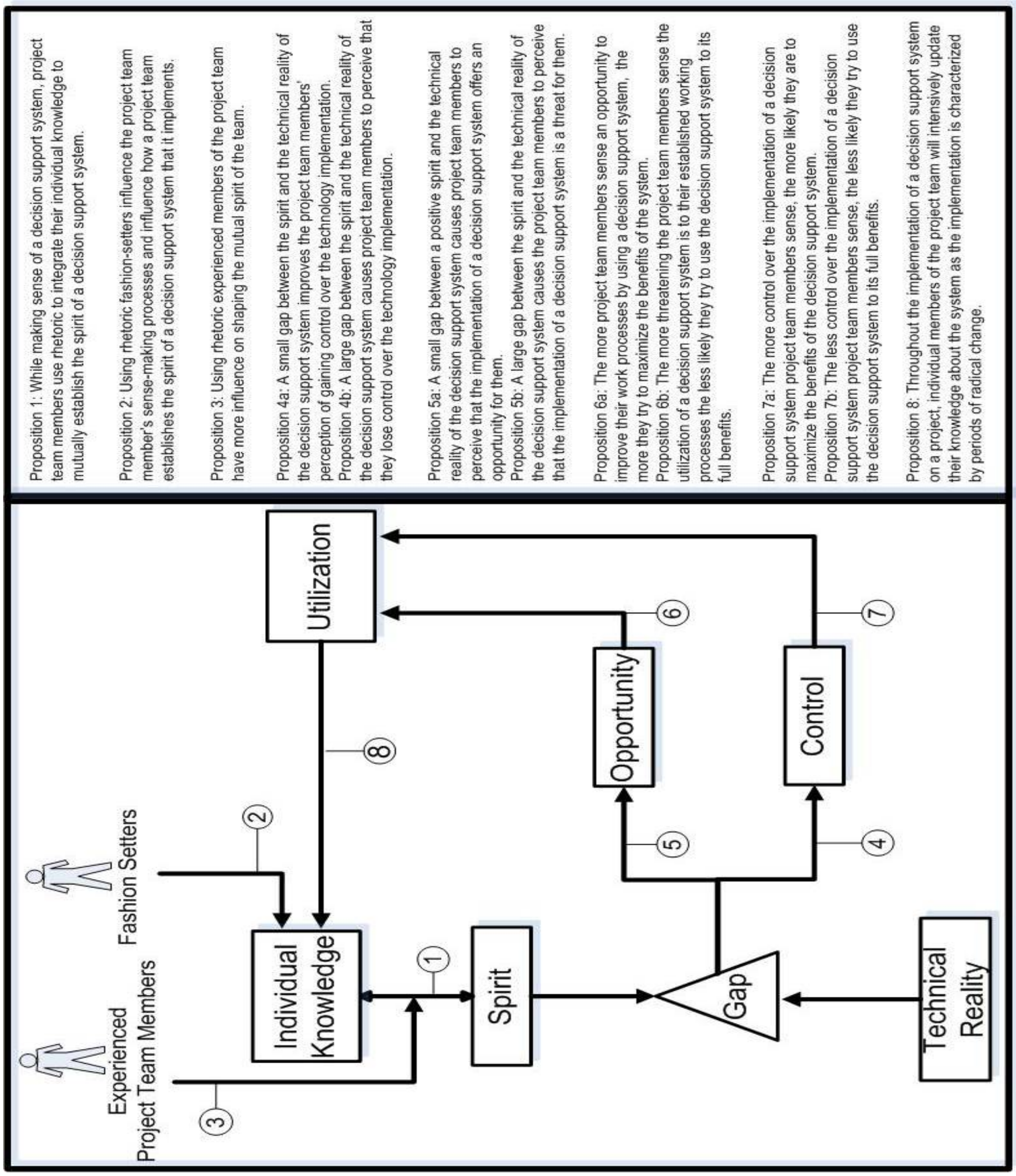

Figure 3-1 - Structuration Model of Grassroots Decision Support System Implementation

3.4.1 Establishing the Spirit of a Decision Support System from Individual Knowledge

According to socialization theories (Berger & Luckmann 1990: 24; Cook & Brown 1990) we posit that while using a decision support system, the project team members seek to make sense of how to integrate the decision support system with their existing thought patterns. During these integration efforts, they jointly redefine the properties of the decision support system in the local context of their social system and environment into properties that the team can understand (Weick 1977: chapter 8). In this way, the project team generates a common stock of knowledge that describes the spirit of the application (Majchrazak et al. 2000; DeSanctis & Poole 1994). This spirit accounts for how project team members perceive the characteristics of the technology within the local social and environmental context as it is jointly understood subjectively by the project team. For example, the spirit accounts for the project team members' understanding of how to use the decision support system to capture technical knowledge, of how to use the system to share technical knowledge, and how the project team members think they can utilize the system during decision making. In this way, the spirit legitimates the technology within the project team's social system and environment (DeSanctis & Poole 1994; Poole & DeSanctis 1990).

During the process of establishing the spirit of the decision support system language is important to enable the project team to make sense of new experiences: the "sociology of knowledge pre-imposes sociology of language" (Berger & Luckmann 1990: 185). Berger and Luckmann (1990) describe the influence of language on the sense making process in detail. At first, the reality of a new problem is distorted as there is no language available to make sense of the problem (ibid.: 26). Over time individuals develop new categories and frameworks by regrouping the particulars of their "language processing" (ibid.: 68), and solutions to the problem can be integrated into the available stock of knowledge. This available stock of knowledge, in turn, affects the interaction with others with respect to the problem at hand, or with respect to other problems (ibid.: 41). Within a project team, language, therefore, allows the individuals within the group to share their experiences, integrate individual knowledge into a common stock of knowledge and to jointly establish the spirit. Throughout this sense making process about a decision support system, rhetoric, has an important role (Clark 1987: 34). We summarize this argument in Proposition one.

Proposition 1: While making sense of a decision support system, project team members use rhetoric to integrate their individual knowledge to mutually establish the spirit of a *decision support system.*

As we characterize project teams as organizational groups that work in uncertain conditions, individual members often lack the knowledge to make rational choices about how to use a decision support system to improve organizational efficiency (Meyer & Rowan 1977; DiMaggio & Powell 1983; Thompson 1967). In these settings individuals tend to understand and implement new technologies by imitating others (Abrahamson 1991; Ford & Ford 1995). Therefore, organizations from outside the group influence the rhetoric that members of the team use when they talk about the technology. Abrahamson terms this process fashion setting (1996).

Abrahamson (1991) illustrates how organizations that are not part of the project team, such as consulting firms, universities, academic gurus, technology managers of centralized corporate departments or even members of the company's marketing department (Hirsch 1972; Eccles et al. 1992; Mickelthwait & Woolridge 1996) influence organizational members to adopt new technologies. Doing so, fashion setters rely on their ability to inspire the adopting organizations rhetorically (Czarniawska-Joerges 1988; DiMaggio & Powell 1983). Proposition two integrates the fashion setting theory into the grassroots model.

Proposition 2: Using rhetoric fashion-setters influence the project team member's sense-making processes and influence how a project team establishes the decision support system's spirit.

So far, we explained how a project team mutually establishes a spirit of a decision support system that describes the system's properties as they are perceived in the local environment of the team. We also explained how fashion-setters influence this process from the outside of a project team by influencing the project team members' sense-making about the technology. As the spirit is a combination of the members' individual knowledge, next, we synthesize theories that describe how the individual members combine their knowledge to form the technology's spirit.

Before describing how the knowledge of individuals influences the formation of the technology's spirit it is important to understand how individuals develop knowledge about the technology. Thus, we first explain how individuals gain knowledge, by again drawing on structuration theory with its duality of social construction of reality and social construction by reality. An individual's existing knowledge is both medium and outcome at the same time (Giddens 1986: 25; Cook & Brown 1990; Feldman 2000; Sudnow 1965; van Maanen 1978). Thus, in the context of a technology implementation, on one hand, project team members can use knowledge about prior events that occurred during the implementation of other similar decision support systems or during the current implementation to make sense of the implementation effort (Forman 2005). On the other hand, knowledge is updated according to how the team members make sense of new aspects by interacting with the technology and "producing and re-producing descriptions" (Heritage 1984: 124) and rules that define the spirit of the technology. Empirical research shows that during this process the existing structures within the group, the technology's characteristics, and the local environment constrain how the individual group members make sense of the technology (Orlikowski 1996; Barley 1986; Barley 1990; Taylor 1995; Smith 2005).

Through rhetoric, individuals then integrate their individual knowledge into the project team's common stock of knowledge and accordingly define the spirit. Thus while the fashion-setters have some influence on the spirit of the technology, we assume that the project team members decide internally how to implement the decision support system according to the spirit they mutually establish. As specialists from various backgrounds form the team, different project team members may uniquely influence how the decision support system is utilized jointly by the team (Cohen & Bailey 1997). We expect that some members of the team have more influence over how the spirit is developed than others. To understand how the common spirit within a project team develops, it is, therefore, important to understand which project team members have a strong rhetoric influence and which don't. In general, the individual status among peers gives credibility that influences the verbal interaction in the organization (Cicourel 1990; Pfeffer 1992: chapter 1). This status among peers is often attributed to the professional nature and concerns about someone's competence. In organizational environments where objective information is not readily available, which is usually the case on projects, individuals need to rely on tacit knowledge to complete their daily working tasks in a professional and competent manner (Kreiner 1995).

Individuals can only acquire such tacit knowledge if they have previously spent a certain amount of time solving similar tasks (Polanyi 1966; Cook & Brown 1990). Accordingly, we propose that the status of an individual in a project team is mainly influenced by the tacit knowledge that peers attribute to the individual and thus to the prior experience the individual brings into the project team. We hypothesize that it is most likely that experienced members of the project team influence the verbal interaction, and therefore, in turn, the commonly understood spirit of the decision support system. Proposition three links the theory about who can most influence the rhetoric within a project team into the grassroots implementation model.

Proposition 3: Using rhetoric experienced members of the project team have more influence *on shaping the mutual spirit of the team.*

So far we have reviewed how a project team develops the spirit of a decision support system during its implementation by integrating rhetoric from outside fashion-setters and from the experienced members of the project team. Next we review how this spirit influences individual project team members to make sense of the decision support system. This, in turn, influences whether project team members perceive the use of the decision support system as an opportunity and how much control they perceive they have over the implementation of the system on their project. Understanding this sense-making process is an important step towards understanding how project team members finally decide how to utilize the technology.

3.4.2 Evaluating control and opportunity by making sense about the spirit and its relation to the technical reality

Researchers have empirically observed that there is a gap between how people talk about the implementation of a technology in their organization and how they individually implement and utilize the technology (Zbaracki 1996; Macri et al. 1999). Thus we assume that, independent of the objective technical reality of the decision support system, the spirit of a system defines the characteristics of the system that the project team members jointly perceive. This subjective spirit does not represent exactly the objective technical reality of how project team members utilize the system and the potential of how the system can actually support the team. Therefore, during the use of the decision support system the members will experience a gap between the spirit and the system's technical reality or, in Zbaracki's, words, between rhetoric and technical reality.

Zbaracki (1996) or Macri et al. (1999) showed empirically how the size of the gap between rhetoric and technical reality influences how organizational members make sense about the implementation process. They show how a large gap between rhetoric and the technical reality influences the organizational members' sense making process in two ways. First, a large gap between rhetoric and technical reality usually leads to unrealistic expectations for how the use of the technology, which in turn leads to ignorance about the technology's functionality. Second, a large gap between rhetoric and technical reality may foster intimidation among organizational members caused by the need to implement technical concepts that are not well understood.

Applying Zbaracki's and Macri's findings, the grassroots model assumes that project team Members determine how much control they have on the implementation and use of the decision support system by how well they can explain wanted and unwanted outcomes of the implementation. This explanatory ability of individuals is based on the knowledge that they possess (Friedman & Lackey 1991: 23). We, therefore, posit that a small gap between the spirit of the decision support system and the decision support system's technical reality improves the control individual project team members feel they have over the implementation. We formulate Proposition 4 accordingly:

Proposition 4a: A small gap between the spirit and the technical reality of the decision support system improves the project team members' perception of gaining control over the technology implementation.

In contrast, if individuals are ignorant about the decision support system, due to a large gap between the spirit of the system on the project and the technical reality, it is most likely that they feel less control over the implementation.

Proposition 4b: A large gap between the spirit and the technical reality of the decision support system causes project team members to perceive that they lose control over the technology implementation.

Empirical studies show that the loss of control due to a large gap between rhetoric and technical reality is closely related to the intimidation individuals feel while working with new technologies that change the social order (Barley 1986; Rogers 2003; Beaudry & Pinsonneault 2005). Such feelings can occur whether the technical reality is incompatible with the project team's existing routines (Levitt & March 1988) or whether the spirit of the technology is not adjusted to the technical reality (Orlikowski 1996; DeSanctis & Poole 1994). With respect to sense-making processes, we hypothesize, therefore, that a large gap between spirit and technical reality causes individuals to perceive the implementation of the technology as a threat to their established working routines. On the other hand, members of a project team perceive the use of the decision support system as an opportunity, only if the gap between spirit and technical reality is small and the spirit of the technology reflects the objective local social and environmental circumstances well. Of course, this premise only holds if the spirit and the technical reality is positive and suggests that project team members will be able to benefit from using the system. We use Proposition five to explain how project team members perceive whether the implementation of a technology is a threat or an opportunity for them.

Proposition 5a: A small gap between a positive spirit and the technical reality of the decision support system causes project team members to perceive that the implementation of a decision support system offers an opportunity for them.

Proposition 5b: A large gap between the spirit and the technical reality of the decision support system causes the project team members to perceive that the implementation of a decision support system is a threat for them.

In the previous sections we developed a number of propositions that together represent a theoretical model of how the members of a project team individually make sense of a decision support system within their local social system and environment and how they use rhetoric to mutually develop the spirit of a decision support system. In this section we proposed how this spirit influences how project team members make sense of how much control over the implementation of a decision support system they have and how much opportunity the implementation offers. Based on these propositions, we can now explain how project team members decide to use a decision support system accordingly.

3.4.3 Use according to the outcomes of the sense-making processes

A number of researchers have developed theories of how perceptions generated during sense-making influence individual decisions of how to use a new technology. In relation to subjective sense-making processes, Davis developed a widely used theoretical model of how the perceived usefulness and the perceived ease of use influence the behavioral intentions to use the technology (Davis 1989; Davis et al. 1989). Extending Davis' theory, Beaudry and Pinsonneault (2005) explain how individuals' sense-making processes influence how they utilize a decision support systems integrating Lazarus' (2000; 1984; 1966) coping theory and the empirical and theoretical technology implementation literature (Rice & Rogers 1980; Ives & Olsen 1984; Clark 1987; Leonard-Barton 1988; Majchrzak et al. 2000; Poole & DeSanctis 1990; Sokol 1994; Tyre & Orlikowski 1994; Orlikowski 1996; Tyre & Orlikowski 1996). In accordance with the propositions of the previous sections, they propose that project team members utilize a new technology according to how they decide whether the decision support system is a threat or an opportunity and how much control they have over its implementation. According to the decisions made during their sense-making processes individuals employ various coping strategies. If individuals sense that the use of the technology offers the opportunity to improve their work processes and they sense control over the implementation they try to maximize the benefits they can realize by using the technology. However, if individuals sense little control and that the technology is a threat they are not likely to use the technology to its full potential.

Proposition 6a: The more project team members sense an opportunity to improve their work processes by using a decision support system, the more they try to maximize the benefits of the system.

Proposition 6b: The more threatening the project team members sense that the implementation of a decision support system is to their established work processes the less likely they try to use the decision support system to its full benefits.

Proposition 7a: The more control over the implementation of a decision support system project team members sense, the more likely they are to maximize the benefits of the decision support system.

Proposition 7b: The less control over the implementation of a decision support system project team members sense, the less likely they try to use the decision support system to its full benefits.

Up to now, we have explained how a project team jointly defines the spirit of a decision support system during implementation and how this spirit influences the decision of the individual members of the project team about how to utilize the technology. To complete the cyclic nature of our model in the sense of structuration theory, we finally need to explain how the use of the technology influences the individual knowledge of the members of the project team.

3.4.4 Updating individual knowledge by utilizing the decision support system

Tyre and Orlikowski (1996) describe two distinct ways of how individuals update knowledge about a technology while using it. First, drawing on Levinthal's and March's (1981) theory of adaptive organizational search they propose that individuals update their knowledge about a technology by using it within a relatively stable period of operation. Individuals in such periods will tend to institutionalize the effective use of the technology (Scott 2001). Tyre and Orlikowski argue that once the use of a technology is institutionalized, no further updating of individual knowledge occurs. Second, Tyre and Orlikowski propose that there will be times of “intensive episodes of change” during which individuals are forced to experiment with the technology to match its features to the environment. During such phases project organizational members update their knowledge about the technology in a far more extensive way than during stable periods of operation.

We hypothesize that due to the temporal nature of a project team it is most likely that an institutional use of a decision support system is not reached before the end of the project. Furthermore, we expect that most decision support implementations will represent radical organizational changes as a slow adjustment in the temporary organization of a project team is not efficient. Thus we assume that the implementation of a decision support system by a project team is largely characterized by intensive episodes of change. Therefore, a constant updating of the individual knowledge of the project team members takes place throughout the implementation. We finalize the grassroots model by formulating proposition eight accordingly.

Proposition 8: Individual members of the project team will intensively update their knowledge about the system throughout the implementation because the implementation is characterized as a period of radical change.

In this section we have developed a theoretical model that explains grassroots implementation processes of decision support systems in project teams. In the next section we discuss a number of theoretical implications of our overarching framework and, in this way, position it within the broader context of organizational theory.

3.5 Theoretical Implications

The grassroots model of decision support system implementation by project teams explains the process by which a project team mutually and continually generates the spirit of a new technology that it implements on its project and how it utilizes the system according to the outcomes of the sense-making processes. By focusing on project teams our model is tailored for decision support system implementations within flat hierarchies or within organizational situations in which the use of a system cannot be mandated. In detail the framework proposes that while making sense about a decision support system project team members, who gain a feeling of control over the decision support system implementation and who become knowledgeable about the system try to use the system in a way that the system’s possible benefits are maximized. In contrast, project team members who conclude that they do not have control over the decision support system implementation or who do not gain sufficient knowledge about the system's potential are likely to try to minimize the expected negative consequences of the technology implementation. These project team members are not likely to utilize the new technology and are likely to avoid using the decision support system.

How members make sense of a decision support system is mainly influenced by the spirit of the project team and by the individual knowledge of the project team members about the reality of the technology within the local organizational and environmental context. How much knowledge about the decision support system and how much control over the implementation the members of the project team perceive is, in turn, dependent on the size of the gap between the common stock of knowledge manifested in the spirit of the decision support system and the technical reality about the potential the system offers.

This model explains a number of factors of the grassroots implementation process that are necessary to implement complicated technologies in complex organizational environments - phenomena that existing micro-social models of technology implementations, if applied individually, cannot explain. First, due to the duality between individual and group level processes the model explains technology implementations that are dependent on how well the decision support system is integrated within the established working processes of a group. Only when the common social spirit of the decision support system matches how individuals experience the reality of the technology within the local social organization and environment will individuals start using the technology efficiently. Second, by explaining how individuals influence the spirit of the project team based upon their individual experience the model explains technology implementations within organizations with flat power structures that rely on concertive mechanisms of control.

In the rest of this section we show in detail how the application of sense-making theory to the field of technology implementation and our subsequently derived propositions integrate and complement the wider field of organizational science and management information science. In particular, we show how our model complements theory in the areas of organizational choice, organizational change and multi-level theory of organizations. We conclude the section by analyzing the boundaries and limitations of the model.

3.5.1 Organizational Choice

Most innovation and implementation studies are based on one of two models: The rational choice model or the imitation perspective (Abrahamson 1991). The rational choice model assumes that organizational members are able to specify their goals and preferences of how to use a technology with a high degree of certainty (March 1978). On the other hand, the institutional perspective assumes that organizational members imitate the use of technologies by other agents (Scott 2001; DiMaggio & Powell 1983; Thompson 1967). Such agents are , for example, fashion setters who legitimate the use of a technology rhetorically (Abrahamson 1996). Scholars, however, have argued that these two models cannot, individually, explain the processes that occur during the implementation of a new technology by an organization (Abrahamson 1991; Clark 1987: 58).

Rational choice models assume that organizational members make their choices in situations characterized by highly certain environments. Unfortunately, most organizations do not operate in such environments (March & Olsen 1979; Meyer & Rowan 1977), and this is especially true for project teams (Kreiner 1995). Therefore, the rational choice model cannot explain the innovation and implementation processes within project teams well. On the other hand, the institutional model reduces organizational actors to “judgmental dopes” that are not able to make rational sense about their goals, means, and ends by themselves (Heritage 1984:111; Garfinkel 1967: 68) and only imitate what they see others do. This neither reflects the situation of the sense-making of the project team members well in which the members start to implement a decision support system in their local environment by subjectively evaluating the potential of the system at hand while at the same time the objective technical reality of the system influences their sense making.

In the spirit of structuration theory (Giddens 1986), our model integrates these two perspectives. First, the model explains the institutional or imitative perspective of actors. Proposition one, two, and three explain how actors within an organization acquire new language by observing others, be it fashion-setters from outside their organizational group or experienced project team members from within. They then integrate this new language into their personal knowledge and support their sense-making processes about the implementation of a decision support system in this way. Second, the model also explains the influence of each individual’s rational choices. Proposition eight explains that project team members start making sense about a new technology using rational thought processes by interacting with the technology during use.

Overall, the model explains how actors try to implement a new technology rationally by using what was already known by the actors before the implementation, what knowledge was acquired by imitating actors outside the project team, and what knowledge was acquired while using the technology.

3.5.2 Organizational Change

Most existing theoretical models to describe general change within organizations are either structural determination models or social evolution models (Giddens 1986: chapter 5).

Davis' (1989) technology adaptation model or Goodhue's (1995) task-technology-fit model are examples of structural determination models. These models assume that social or technological constructs, such as perceived ease of use or the fit between the features of a technology and the tasks that an organization works on, determine constructs that describe the use of the system, such as individual use or effective use of the technology. Structural determination models disregard temporal constructs that influence the project team's work, such as innovative maximization of the benefits of the technology during use that occurs when members of a project team feel control over the implementation and possess a good knowledge about the technology itself (Propositions six and seven). Furthermore, structural determination models do not explain the influence of changing project team internal conditions. To explain technological implementations, especially within complex settings, it is important to understand how organizations change over time (Davis & Marquis 2005; Scott 2001; Barley & Tolbert 1997) and how environmental influences affect the implementation efforts (Giddens1986: 229).

In addition to structural determination models, social evolution models assume that technology implementation efforts by organizations develop a dynamic that continually improves or impairs how organizational members use a technology (Leonard-Barton 1988; Tyre and Orlikowski 1996). Often these models specify a sequence of cyclic stages through which the implementation of a technology evolves. Evolution models are better suited to explain the change of project teams with respect to the implementation of decision support systems than structural determination models. However, they do not adequately account for the constant changes (Giddens 1986: 229) that characterize projects and how these changes influence the technology implementation irregularly. Majchrazak et al. (2000) have shown that evolution models do not work in the context of implementations of complicated technologies and that such implementation processes can be at best described as discontinuous and not as a continuous improvement or impairment to some final state of system use.

In contrast to evolution models, the constructs in our model explain discontinuous changes in the individual effectiveness of use of the decision support system. The model explains such discontinuities with the influence of fashion-setters from outside the project team (Proposition 3) and with the influence that a successful or unsuccessful use of the decision support system in the local environment has on the spirit of the decision support system (Proposition 8). Thus the model explains why project teams abandon an initially promising implementation, or how implementation efforts that started inefficiently become very successful. Additionally, the model explains periods in which the implementing organization utilized the technology very efficiently, while it also explains times when the technology is not utilized at all (chapter 2, this volume).

3.5.3 Multilevel Organizational Theory

Most of the implementation research this paper reviews does not account for implementation phenomena across the different levels of an organization. In the context of a project team it is, however, important to explain how the sense-making and usage decisions during the implementation at the individual level influence and are influenced by the team level. Most of the existing research we reviewed analyses only one organizational level. For example, Abrahamson (1991), Tyre and Orlikowski (1996) or Markus (1983) focus on how industries or firms implement a specific technology. These models usually consider the technology as adopted by an individual, if the technology has successfully been delivered to the individual. These macro models usually do not consider how individuals use the technology once it has been delivered. On the other side of the scale, micro models only observe how individuals make sense of a new technology and subsequently use it according to the outcomes of individual sense-making processes (Davis 1989; Davis et al. 1989; Goodhue & Thompson 1995; Beaudry & Pinsonneault 2005). These models largely disregard the social influences of peers during the sense-making processes. Finally, research that focuses on the group level (Barley 1986; Orlikowski 1996; Majchrzak et al. 2000), in general, disregard influences from the macro level and to some extent influences due to individual sense-making and use processes. Furthermore, as mentioned before, most of these studies assume that the technology implementation is driven by actors at the macro level, like a company's top managers or executives. Thus, they do not explain grassroots implementation efforts well that need to be driven from individuals at the operational level of an organization.

In our model the constructs of technical reality and the spirit of a technology create a link between individuals and the team during the implementation. On one hand the technical reality largely defines how individuals within the team make sense of the technology while they directly interact with the system (Proposition 8). On the other hand our model considers the spirit as the connecting construct between the individual and the team. To jointly implement a new technology the team needs to create a common social stock of knowledge (Proposition 1). As with most multi-level constructs (Klein & Kozlowski, 2000), this common stock of knowledge is not simply a combination of the sum of the individual knowledge. Our model explains how the spirit emerges in different forms and in non-uniform patterns. Individual knowledge about the technology coalesces to form a common stock of knowledge if individuals communicate their specific knowledge (Proposition 1). Our model proposes that his process is mediated by the experience that project team members attribute to their peers (Proposition 2) and by the influence of fashion setters on the individual knowledge of project team members (Proposition 3). With these propositions, the model can, for example, explain situations where the spirit of the technology does not reflect the knowledge of the most technology-savvy person in the team as non-technology-savvy but experienced project team members are in the position to shape the spirit according to their personal opinions.

Additionally, with proposition three our model accounts for the team's internal non-formal power structure while project team members make sense by assuming that the positions of the more experienced team members with respect to the tasks that the team needs to work on determines what is commonly known within the team. It is likely that this power structure within the team changes according to the tasks and problems the team works on at different times as project teams are set up to integrate members with different experiences to solve different tasks and problems. Finally, our model also accounts for the different social macro settings in which the team is embedded by explaining that fashion-setters influence the sense-making process. Summarizing, our model accounts for the non-uniform emergence of the spirit across two organizational levels during technology implementations accounting for possible conflicts among project team members or the formation of coalitions within the team (Brown & Kozlowski 1997, 1999).

3.5.4 Limitations and Suggestions for Future Research

In developing the model we have synthesized a large and disparate body of research on information system management and organizational theory with respect to the implementation of technology. We have moved the field forward through the development of several theoretical propositions. However, while we are confident that our model describes theoretical aspects of the grassroots implementation of decision support systems by project teams, future empirical research needs to validate our theoretical propositions in specific contexts of decision support system implementations by project teams. In this way, researchers can verify the internal and external validity of the model and ensure that it explains different implementation processes in different practical settings.

Due to our focus on the sense-making process within a project team there are two main theoretical omissions of our model that are worth discussing. The first one is that the model assumes that project team members are able to adapt their work processes and the features of the decision support system to achieve effective decision support for the project team members. The model therefore does not account for technical characteristics of the decision support system. In cases where the system's objective technical reality does not allow the successful mutual adaptation of the system and the project team's work routines, other theoretical models like routine based learning (Levitt & March 1988) or task technology fit models (Dishaw & Strong 1999; Goodhue 1995; Goodhue & Thompson 1995; Zigurs &

Buckland 1998) are more appropriate to explain why a respective decision support system implementation failed. The second main omission is that the model does not account for factors that influence the use of the decision support system other than the perceived control or opportunity of the members. It is quite obvious that in complex project environments the differences in the use of the system might be explained by the highly variable situations the system is used in. In such highly variable situations, we expect that experiences with the use of the system are also highly variable. The model cannot show the relationship between how project team members learn about the decision support system and highly variable experiences of the members within the project environment.

Furthermore, except for the proposition that experienced project team members have a greater influence on the construction of the spirit than inexperienced ones, the model does not consider informal power structures within the project team well. This shortcoming stems from the application of Berger and Luckmann's socialization theory (1990) and sense-making theories (Weick 1995) that largely remain silent about power differences of organizational members during the social construction of reality. Furthermore, decisions of how to implement a decision support system are not made jointly by the project team. Most likely negotiation processes take place which are influenced by the different interests, cultures, and past experiences of the project team members. The model cannot explain the different motives and interests that result from this difference of the project team members.

Future research therefore should aim at introducing constructs that explain the often complex and fluctuating informal power structures in project teams and their influence on decision support system implementations.

Another limitation of the model is that we specifically developed it to explain the implementation of decision support systems. The model may not be readily applicable for the implementation of other systems, such as management information systems that project team members use to simply store data and support information distribution among the participants of a project by generating scheduled reports. The model might also not work well for electronic data processing technologies that fully automate the solution of tasks and thus do not require any decision making by the project team members themselves.

While our model explains grassroots implementation processes in detail from the viewpoint of the implementing project team and its individual members, we have said little about its effects on other organizational groups that have a stake in the decision support implementation. The model does not explain how the grassroots decision support system implementations - and especially the constant redefinition of the needed requirements for the system according to the tasks at hand - influence the work of the project team's cooperation's upper management that is interested in improving the productivity of the firm across various project teams by successfully implementing decision support systems company wide.

Other researchers have addressed the problem of how project-based companies implement new technologies company wide (Brady & Davies 2005). The next section complements this research by developing a number of recommendations for how technology managers can support the implementation of a decision support system by a single project team. Doing so, we draw on our experience in supporting the implementation of decision support systems on a number of large construction projects (Collier & Fischer 1995; Haymaker & Fischer 2001; Khanzode et al. 2006a; Khanzode et al. 2006b; Hartmann et al. 2005; Hartmann & Fischer 2007; Hartmann & Fischer forthcoming). However, future research needs to validate whether these recommendations allow the successful macro-management of decision support systems in project-based companies.

3.6 Practical Implications

This paper shows that the traditional models of technology implementation do not adequately describe implementations within the non-hierarchical environments of project teams (Slaughter 2000) nor explain the implementation of technologies whose use cannot be mandated, such as decision support systems (Majchrzak et al. 2000). Therefore, researchers suggest that project-based companies that traditionally apply implementation strategies based on these models restructure their technological management efforts (Brady & Davies 2005). The model that we present in this paper can be a helpful tool while restructuring these efforts as it shows how a single project team makes sense about a decision support system and how the members of the project team start using the system according to the outcomes of the sense-making process. The framework explains two paradoxical situations that project-based companies face during their efforts to implement decision support systems: the fashion setting paradox and the process-product paradox. This section explains these two management paradoxes and provides recommendations for how to manage them.

The first paradox stems from the duality of the technical reality and the spirit of the decision support system and the influence of fashion-setters on this spirit (Proposition 3). What is said matters, and, therefore, people tend to believe what fashion-setters say about a decision support system (Ford & Ford 1995). Abrahamson (1991) even postulates that technically inefficient innovations might diffuse through organizations if fashion-setters promote them. The reason for this is that, in any interaction, teams “try to sustain the definition of the situation that they try to perform” (Goffman 1973: p. 66). Fashion-setters attempt to create a belief that the decision support system they champion is the most efficient means to attain an important goal for the project team. Often this is done by describing how a few other successful project teams have implemented the technology (Abrahamson 1996). By doing so, the fashion setters focus on how the decision support system was implemented by a different project team that operated in a different environment. Technical requirements specific to an implementation of the decision support system in the environment of the adopting project team are most likely omitted during this interaction. Independent of whether the fashion setters try to propagate a technology that effectively supports the decisions of project team members or not, they will stress positive facts while they try to exclude negative facts (Goffman 1973: p. 66). Thus the previously stated argument holds whether the fashion setters market the most technically efficient decision support system or whether the fashion-setters market technologies that they think will be most profitable for them. In the end, it is very likely that fashion-setters spread rhetoric about technologies through the technology adopting group that does not adequately represent the adopting group's technical reality. According to our model, the gap between the spirit of the technology and the technical reality is widened in this way and project team members use the decision support system less efficiently (Propositions 5-7).

Even though fashion-setters are most likely to widen the gap between the spirit of the system and the technical reality, fashion-setters also make an important contribution to shaping the knowledge about the decision support system of the project team members. Project team members will only engage in change if they understand it (Ford & Ford 1995). Without proposition three the model would represent a closed knowledge loop without the possibility to influence a decision support implementation from outside the project team. However, outside influence is important because outside fashion setters usually understand the features of the decision support system well as they have knowledge about the implementation of the systems on other projects. They can use this knowledge to create a positive attitude of the project team members that not only often leads to the initial team's decision to implement the decision support system, but also improves the understanding of the team members about the decision support system. Thus, while fashion-setters often widen the gap between spirit and technical reality during the implementation, they are also often the most important factor during the project team's decision to adopt a technology.

During our consulting and R&D work with project teams we have seen that companies often try to circumvent this fashion setting paradox by training or hiring software specialists who know the decision support system well and deploy these specialists on the company's projects. Unfortunately, this approach has the disadvantage that the decision support features of the technology are unlikely to be utilized broadly and effectively by the other members of the project team to support decision making, since the technology specialists do not have the tacit knowledge that the experienced project managers in the team have to work on project-related tasks. Therefore, according to Proposition Two of the model, they cannot easily spread their knowledge and beliefs about the decision support features of the technology throughout the team. Thus, the use of the decision support system will most likely be disconnected from the ongoing project management work and thus project management efficiency will not be improved.

The second paradox stems from the duality between the technology products and the processes of how to utilize them. In the traditional technological management model, high level technology managers of the corporation’s centralized IT department decide which technologies are available to all employees of the firm. The corporate technology managers then build processes around the product decision to determine how the employees of the company should utilize the technology. As described earlier, this approach usually fails in a project-based company that wishes to support their employees with decision support systems due to the unpredictable environment in which the technology needs to be implemented (Kreiner 1995). It is not possible for technology managers to predict adequately the needs of the project teams that work on the company’s various projects. Thus, it is not possible for the technology managers to develop general processes of how to utilize the technology throughout all projects of the company.

However, in the context of a project team it is also hard to choose adequate decision support systems and to develop processes for an efficient use within the short life-cycle of a project. Therefore, project teams are in the paradoxical situation that, on one hand, there are no company-specific process solutions that the team can readily use in the local social system and environment without enlarging the gap between spirit and technical reality. On the other hand it is not easily possible within the short period that a project team works together to develop processes slowly and iteratively that will not increase the gap between the spirit and technical reality to an extent that project team members loose their perception of control (Proposition 4) and opportunity (Proposition 5) and stop to engage with the decision support system in effective use patterns (Propositions 6 and 7).

In our consulting and R&D work we observed that sophisticated project-based companies have therefore developed a technology management strategy to support project teams with their implementation of decision support systems that can balance the two paradoxical situations. These companies establish a core group of very knowledgeable technology fashion-setters that have knowledge about a variety of different decision support systems and how they can be applied within different environmental settings of project teams. These fashion-setters then work closely with the various project teams of the company, supporting the members of the teams during their sense-making processes. During their support, the fashion-setters focus specifically on improving the decision making capabilities of the respective project team with decision support systems and not on implementing decision support systems and use processes that are standardized for all projects of the company. In this way the fashion setters balance the two contrasting needs of evangelizing a decision support system to reach initial acceptance of the project team members and to influence the subjective spirit of the project team so that it closely matches the objective technical reality about the decision support system during implementation. Additionally, fashion-setters can support the project team with their technical knowledge and thus the project team is enabled to make the decision of which decision support system to implement and how to utilize it within the short time frame available. From the lessons learned on each of the supported projects, the fashion managers can then start to extract the lessons learned during one implementation and integrate them into a company-wide knowledge base as it is described by Brady and Davies (2004). Using this knowledge base, other project teams can support their sense-making processes by using the lessons learned as ideas to improve the implementation of a decision support system in its local environment as it is described by Smeds et al. (2003). The fashion setters can then slowly and iteratively generalize use scenarios that supported a number of different project teams and in this way iteratively develop standardized guidelines for the whole company.

One inherent problem of focusing on the support of local decision making tasks is that different project teams of one company use different decision support systems to accomplish similar decision making tasks. However, there is the need for project-based companies to aggregate data that are managed by these decision support systems to support the decision making tasks of upper management that manages the resources of the company. We suggest that project-based companies balance this problem by first focusing on the support of local project-centred decision making by implementing custom tailored systems. The databases of custom tailored systems can then be linked without much interference of local project decision making routines using state-of-the-art database and data mining technologies. Such links can the integrate the resource information from all projects of the companies to support executive decision making. This method also yields another advantage for the support of executive management. Our experience shows that project-based companies often rely on systems for data entry to support executive resource planning for the company that are detached from the ongoing decisions on the project itself. Due to the detachment of the data entry tasks from the ongoing decision making tasks project teams often consciously or unconsciously enter data into these systems that are not up-to-date or does not reflect the prevailing information on the project adequately. If project teams use information systems that support local project decisions, it is more likely that the data project teams store in these systems are up-to-date and reflect the project information adequately and thus, in turn, support the decision making of the strategic management better.

This paper postulates that the traditional top-down innovation management model does not work well for diffusing decision support systems through project teams. This explains why project teams often cannot realize the promising initial benefits of a decision support system implementation. To improve the effective use of decision support systems to support decision making of their employees at the operational level, project-based companies need to shift their focus from a top-down technology implementation strategy towards supporting a grassroots implementation effort from within the project teams of the firm (Davies & Brady 2004). To support such grassroots implementation efforts it is important to understand the sense-making process of individuals and how teams mutually generate the spirit of a decision support system during the implementation. We reviewed the project management, decision support system, and technology implementation literature and applied various sense-making theories to technology implementations results in a model that serves as a starting point for future empirical research in this area. Additionally, the model together with the management recommendations we describe in this section can be a starting point to support technology managers who plan to support project teams to implement decision support systems.

3.7 References

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4 Implementing Decision Support Systems with Project Teams Using Ethnographic Action Research

4.1 Abstract

Architecture, engineering, and design (AEC) projects are characterized by a large variation in decision making routines between different projects and on single projects over time. Therefore, it is difficult to develop and implement systems to support such project-based decision making routines. Decision support systems for projects not only need to closely match project decision making routines, but they also need to be highly adaptable to unique requirements that project managers have. To address these challenges, this paper presents a project-centric research and development methodology that combines ethnographic observation of practitioners working in local project organizations to understand their local requirements and the iterative improvement of decision support systems directly on projects in small action research implementation cycles. The paper shows the practical feasibility of the theoretical methodology using decision support system development cases from AEC projects in North America and Europe. The cases provide evidence that ethnographic action research is well suited to support the development and implementation of decision support systems. In particular, the evidence shows that the method enables the identification of specific problems in the daily work of AEC practitioners and offers important insights on AEC project specific organizational decision making routines. Additionally, the evidence shows that the method enables the adaptation of decision support systems to the changing requirements on projects.

4.2 Introduction

The Architectural, Engineering, and Construction (AEC) industry produces complex, customized, and highly unique products. Therefore, it organizes its work force through temporary projects (Gann & Salter 2000). Due to the temporary and highly complex nature of projects, decision making routines are characterized by a paradoxical situation. On one hand, project information that practitioners need to make decisions is updated frequently, often tacitly in the heads of the engineers as decision making strongly relies on individual experience (Kreiner 1995). On the other hand, due to the large number of the stakeholders involved, a frequent exchange of information is necessary so that AEC practitioners can make adequate decisions. To overcome these problems, practitioners use more and more information and communication technologies to support AEC decision tasks. The AEC industry has identified the implementation of decision support systems as one of the most important areas of technology development to improve the productivity of AEC projects (Liberatore et al. 2001; Teicholz & Fischer 1994; Turk 2006). However, our experiences from a large number of projects show that often these systems are not leveraged to their full potential benefits (Hartmann & Fischer forthcoming)..

From a technological standpoint this problem can be attributed to two factors. First system developers have found it difficult to gain the enhanced understanding of the tacit process knowledge of the AEC professionals to develop decision support systems that support product and process management decisions. Therefore, so far, system developers have not been able to adequately formalize project decision support routines in decision support systems. Second, the existing platforms cannot be adjusted easily to decision support routines of specific AEC projects. However, as practitioners tend to use different decision making routines for the same tasks from one project to another and even on one single project as requirements change (Randall et al. 2007:29) the possibility for practitioners to adjust decision support systems to local requirements is very important. These two problems of existing decision support systems solutions have caused a large gap between how practitioners can use decision support systems solutions on projects today and the potential benefits that technology managers and software companies promise. This gap, in turn, is one of the reasons that causes the low acceptance of decision support system solutions among AEC practitioners (chapter 2 and 3 this volume).

Grassroots models of decision support system implementations by project teams (chapters 2 and 3 this volume) suggest that a successful implementation of decision support systems on projects need to be driven by the project managers working at the operational level themselves. However, project managers often lack in-depth knowledge of software implementation and development Therefore, it is important that technology developers support project managers during such grassroots implementations. This paper shows how technology developers can apply ethnography (Randall et al. 2007; Spradley 1979) and action research (Baskerville & Wood-Harper 1996; Checkland & Scholes 1990; Susman 1983) methodologies to support such grassroots implementations. In detail, the paper proposes that ethnographic action research methodology is well suited to support grassroots implementations because project team members are actively involved during the development and implementation processes. The paper also provides case based evidence for this argument from the application of ethnographic action research on a number of AEC projects. Summarizing, the findings from the cases show that the methodology is well suited to identify decision making routines that AEC professionals face during their day-to-day work, to understand these decision making routines well, and to adjust decision support systems to these routines and to changes to these routines throughout the life-time of a project and across different projects. In this way, the paper contributes to existing theories of ethnography and action research by showing the applicability of the ethnographic action research method for the development of decision support systems for the AEC industry.

The paper is structured as follows: The first section describes factors that contribute to a heightened complexity of decision making routines on AEC projects compared with processes prevailing in other industries. The second section briefly assesses the current state of decision support-related technologies in the industry and decision support system related research. The third section explains the functionality that decision support systems need to have so that project teams can successfully implement them. The fourth section introduces the project-centric research and technology development and implementation methodologies and shows how they can support the successful development and implementation of decision support systems. The fifth section traces decision support system implementations on a number of AEC projects to show how the methodologies have been applied in practice and provide first evidence for the power and generality of the ethnographic action research methodology to support decision support system implementations by project teams. We conclude the paper by analyzing the cases with respect to their relevance for the field of project-centric systems development and by elaborating on the limitations and boundary conditions of the presented methodology.

4.3 Complexity on AEC Projects

AEC projects don't have a long history or future, and, thus develop their own routines to exchange and communicate information that project managers need to make decisions. The uniqueness of local project teams is further strengthened as different organizations with their own social cultures work together and need to interact frequently (Dubois & Gadde 2002; Kreiner 1995; Taylor & Levitt 2007). Therefore, decision making routines differ across projects and even change over the life-cycle of a single project. How engineers make decisions on AEC projects is therefore highly sensitive with respect to varying organizational routines (Nardi 1996).

Due to the sensitivity of decision making tasks, AEC decision processes, such as building systems design (Korman et al. 2003), constructability review (Hartmann & Fischer 2007; Hartmann et al. 2007), or cost estimation (Staub-French et al. 2003), have been described as knowledge intensive (Eden & Huxman 1996; Yoshioka et al. 2004). Engineers working on these processes not only need to manage the product itself, but they also need to manage the resources required to build this product (Ahuja et al. 1994), such as productivity rates of the design team, drawings needed to visualize the construction plan, or costs of regional materials. Thus, because of the uniqueness of the products that are generated, decision making routines that AEC practitioners need to generate these products are also unique.

As mentioned, project information that practitioners need to make decisions changes frequently. Since it is often virtually impossible to document and track all project information explicitly and since AEC processes strongly rely on individual experience (Kreiner 1995), these changes happen often tacitly in the heads of the engineers. Additionally, AEC practitioners need to manage two dimensions: the product dimension and the process dimension. An example of decision making tasks to manage these two dimensions is, for example, the design of mechanical, electrical, and plumbing (MEP) systems with three-dimensional building models (Khanzode et al. 2006b; Kim et al. 2006; Staub-French & Khanzode 2007). On the product side, a decision support system to support 3D based MEP design needs to support the development of the product itself. On the process side, a decision support system additionally need to support the management of the project's process information, for example, to enable decisions of how different stakeholders resolve conflicts between sub-systems, or whether and how stakeholders need to update project budgets and schedules throughout the design.

Chapter two and three of this volume show that decision support systems needs to be driven by the project team members working at the operational level of the project in a grassroots process. During such grassroots implementations, the influence of project team outsiders on the implementation is limited, as they do usually not possess enough local knowledge to understand the project-specific decision making routines in detail. Furthermore, the success of a grassroots implementation depends on the sense-making processes of the individual members of the team. Only if the members of the team conclude that the decision support system offers an opportunity to improve the decision making processes and if they feel they have enough control over the implementation will they start to use the system to support their decision making routines. Additionally, project team members will continue to use the system and adapt it as needed only if they perceive positive feelings of control and opportunity How much control and opportunity project team members perceive is dependent on how close the perceived potential benefits of using the system reflects the objective potential the system offers locally on the project. Therefore, for a successful implementation, it is important that decision support systems closely represent specific project decision making routines. The next section offers an overview about existing decision support systems for AEC projects and analyzes how well the potential promised benefits these solutions offer fit with their applicability on projects to support decision making tasks.

4.4 AEC Decision Support Systems Today

As we mention previously, practitioners so far have not started to embrace decision support system use widely. We attribute this lack of embracement partly to the large gap that exists between the potential benefits of decision support system solutions to support AEC projects in general and the ability of today's decision support systems to support specific AEC projects in detail. This section discusses two reasons why decision support systems have not yet been able to sufficiently support AEC project decision making routines.

The first reason that hinders a more widespread use is that existing commercial decision support systems do not support the duality of product and process management, which is critical for AEC project management. While existing commercial process management platforms traditionally focus on managing schedules and budgets, product planning and design platforms are concerned with managing the form and functionality of a product. However, as we mentioned previously, AEC practitioners on projects need to manage both dimensions during their day-to-day decision making tasks. The following paragraphs analyze this shortcoming of existing decision support systems in detail.

The AEC industry has a long tradition to support process-management-specific decision making on the project level with respect to cost, schedule and resource management with decision support systems. Additionally, lately researchers have started to develop architectures to integrate product management functionality into these process management decision support systems to support some project decision making routines (Caldas & Soibelman 2003; Hartmann & Fischer 2007). However, most of the state-of-the-art process management systems do not yet use underlying data models to support product management. Usually product information can currently only be stored in production management platforms as unstructured data in the form of file formats that are only supported by third-party software applications. Thus it is not easy for AEC professionals that work on projects to aggregate and incorporate AEC project information across different product and process functions to support integrated decision making by using process management systems alone.

On the product management side, decision support systems enable practitioners to manage the development of a product throughout its life-cycle. For example, PLM solutions allow engineers to make decisions about the status of the development process of a product and, in particular, they enable engineers to manage multi-stakeholder projects (Sääksvuori 2005: chapter 1). One of the main features of PLM solutions is the storage of three-dimensional product data that enables engineers to view the product from different angles and to cut arbitrary sections through it. In this way, PLM solutions can support decision making tasks during the development of the product visually. Furthermore, a product breakdown structure supports the management of related product subsystems. Information from each of the product's sub-functionalities can be aggregated to support the management of the overall product development processes. However, most of the commercial product life-cycle platforms specifically support the manufacturing, automotive, and aerospace industries and thus do not specifically support AEC decision making processes. Furthermore, process management contributes to only about 5% of the functionality of an overall PLM solution (Stark 2005: 407) and thus important project management functionality is missing.

Significant research has been conducted in the area of product management modeling. For example, researchers have developed the Industry Foundation Classes (IFC), a quasi-standard data model to capture three-dimensional representations and related data of buildings (Cheng et al. 2002). Furthermore, commercially available product management applications, so called building information modeling (BIM) tools, are available to support decision making tasks during the development of buildings. Finally, many researchers have developed product management methodologies to enable engineers to collaboratively develop features of a product (Kim et al. 2006; Kiritsis et al. 2003; Park & Seo 2006; Shen & Shao 2007; Tang et al. 2007). However, most of these research efforts had little impact on practice so far.

We partly attribute the low practical impact of AEC research efforts to the fact that researchers do not sufficiently consider process management functionality during their product management research. Only a few studies have addressed the integration of process management functionality with product management models, mainly in the area of change management (Caldas et al. 2005; Haymaker et al. 2004; Mao et al. 2007). Summarizing, similar to the available process management solutions, the existing product management solutions and research efforts often do not align well with project dependent decision making processes on AEC projects and an adjustment to specific project routines is hardly possible (Taylor & Levitt 2007).

The second reason for the slow uptake of existing decision support systems is the low adaptability of decision support systems to local project requirements. This hinders practitioners to integrate the latest research results in their local project's decision making routines. Much research and many software development efforts have focused on developing generalized data models. Therefore, the research results do not consider ways of how AEC practitioners can adjust decision support systems to the varying characteristics of specific AEC projects. Additionally, it is a recent trend that decision support system development started to focus on integrating product and process information from a number of different projects to enable firm-wide resource planning. This in turn, requires a further standardization of the decision support systems across the different projects of an AEC company. Obviously, this standardization is conflicting with the needs to adjust the decision making processes to local project routines.

Finally, software companies have developed most of the existing commercial decision support systems using the traditional product management life-cycle. Only after an intensive invention and software development phase in the software companies' offices that often lasts a number of years, do the software companies try to implement the developed decision support systems on AEC projects (Rogers 2003: chapter 4). Obviously, it is hard to account for local project routines and the ever changing professional requirements with this development model. Even if software companies are willing to support some needed project-specific functions, it usually takes one to two years until the next version of the decision support system that provides the respective functionality is delivered.

This section argues that there exists a large gap between the potential benefits of decision support systems to support AEC project routines and the ability of existing systems to support AEC project routines in a practical context. By reviewing commercial and academic efforts to develop decision support systems for the AEC industry, we show that, so far, no commercial system has been developed that is able to support both dimensions of functional AEC business processes of managing product design and production processes sufficiently. Furthermore, we argue that the low adaptability of t the systems to local project contexts is a second reason for this gap. Due to the decision support system developers' focus on enterprise wide resource management and their long update delivery cycles existing commercial solutions do not offer sufficient functionality to enable project teams to adjust the information management to specific decision support requirements of AEC projects. To overcome these shortcomings, the next section introduces a number of technical requirements for decision support systems that system developers need to consider to be able to reduce this gap between the technical reality and potential benefits of decision support systems.

4.5 Requirements for Decision Support Systems

As the previous section shows, an overall decision support system architecture needs to support product and process management decision making routines for different work tasks of a project. Additionally, the section shows that systems need to be quickly and easily adjustable to local project routines.

To satisfy these requirements, decision support system developers need to address the following three issues:

- System developers need to build up an enhanced understanding of the complex problems that practitioners face during their daily decision making tasks by understanding the duality of managing the product and process at the same time. Only if a decision support system's functionality matches this complex duality of decision making tasks and, in this way, the requirements of AEC practitioners working on projects closely, can the system adequately support project decision making routines (Miles et al. 2002).
- System developers need to develop an understanding about decision making routines on specific projects. Hereby, it is important to understand how practitioners interact with each other. How professionals communicate, in turn, is largely defined by the roles, norms and values of the professionals. Additionally, it is important to gain an in-depth understanding of the different viewpoints of practitiers during decision making (Checkland & Scholes 1990:49; Heath & Luff 1992). As we described earlier, due to the temporary nature of projects, these roles, norms, values, and viewpoints will change from project to project. Therefore, an enhanced understanding of local project contexts is necessary because only if practitioners are able to integrate decision support systems seamlessly in their local project decision making routines, is it likely that they will start using the systems (Taylor & Levitt 2007; chapter 2 & 3 this volume).
- Finally, it is unlikely that stable decision making routines will crystallize in the short life-time of an AEC project. Therefore, system developers need to anticipate that practitioners will change existing decision making processes, after they started using a decision support system. It is most likely that roles, viewpoints to interpret data, norms and values will change even on a single project (Checkland & Scholes 1990:20). Thus already developed and implemented decision support systems might model obsolete processes and might not support the new processes efficiently. It is, therefore, important to enable and support the ability to constantly adapt decision support systems to local project conditions and project challenges (chapters 2 and 3, this volume).

Summarizing, decision support system developers need to gain an in-depth understanding of the product and process management processes and the decision making routines on specific projects. Furthermore, project teams need to be able to adjust developed systems to changing project requirements. The next section will propose a research methodology to support system developers with this task.

4.6 Ethnographic Action Research Methodology

In this section, we suggest that AEC decision support system developers become researchers that apply action research, a well-established method to do case research on projects. Action research is well suited to solve many of the problems we discussed earlier (Baskervill & Wood-Harper 1996). One important characteristic of action research is that practitioners and researchers work closely together throughout the whole research process. The researchers start doing practical project work and the AEC practitioner starts doing research. In this way it is possible to gather and simultaneously verify knowledge about complex decision making routines and how practitioners follow these routines on their respective project. Researchers (Baskerville & Wood-Harper 1996; Checkland & Scholes 1990; Susman 1983) usually describe the action research process as iterative cycles of observations of practitioners, identification of problems, development of technical solutions, and implementation of the developed solutions. This action research process in the area of the design of engineering applications has been shown by, for example, Miles et al. (2002) or Raphael et al. (2007).

Action research methodology stresses that during practitioner observation and data analysis, it is important to gain an in-depth understanding about local project routines from the project team member's viewpoint. This in depth understanding, in turn, then ensures that the developed decision support systems integrate well into the project context. However, action research methodology, in general, does not offer detailed tools and techniques to achieve such an understanding.

Complementing action research, ethnographic research can provide such tools and techniques. While, traditionally, the ethnographic methodology was developed by anthropologists to study human cultures (Spradley 1979), in the last two decades, technology researchers have started to use the methodology to observe the implementation of technologies within social systems to inform the design of the technologies. For example, Suchman (1993) observed the work of flight controllers at airports and their interaction with different flight control systems, Barrett et al. (2005) observed how system administrators managed autonomic computer systems, or Heath and Luff (1992) observed the interaction of control managers of the London Underground with technology. Recent summaries of ethnographic methodologies to support technology design with fieldwork can be found in Randall et al. (2007) or Iqbal et al. (2005). A number of researchers in the AEC industry have already observed and improved the use of technologies by AEC practitioners on projects using ethnographic action research case studies: For example, Jongeling and Olofsson's (2007) exploration of how three-dimensional product models support the scheduling of workflows, Hartmann and Fischer's (2007) exploration of how three-dimensional product models support constructability review, or Khanzode et al. (2006a, 2006b, Staub-French & Khazode 2007) exploration of how three-dimensional models can support the coordination of the product design and production of MEP systems. All of these studies have in common that they closely observed the work of practitioners within their local routines on AEC projects.

The difference between ethnographic studies and traditional research is that researchers try to understand how project team members interpret experiences and create social behavior (Spradley 1979). In other words, the focus of the research is to understand how the professionals act, think, and feel during their daily work. This understanding can then be used to implement and customize decision support systems to the local project culture, instead of trying to force the use of a ready made system that might more or less well support the project team. During ethnographic research, it is, therefore, important to closely follow AEC practitioners during their daily work and learn the language that the AEC professionals speak. Ethnographic action researchers need to become students of the project team members (Spradley 1979:4) learning how AEC professionals create, exchange, and communicate information during their decision making tasks and what artifacts they use to do so.

Ethnographic action researchers need to collect data from different sources, such as passive observations, participant observations, interviews and other documents such as meeting minutes or reports that can support their observations (Yin 2003). Thus ethnographic data collection requires, in general, a very close integration of project team and researchers. Ethnographic action researchers can then analyze this collected data by triangulating the different data sources to inform system design (Eisenhardt 1989; Miles & Huberman 1994). While analyzing these data sources, ethnographic action researchers should not try to formulate product and production processes that AEC professionals might use before they start analyzing the data. Instead, the analysis of data should result in the definition of product and production processes that reflect the work of the local project team members. Furthermore, ethnographic action researchers should constantly compare their previously defined processes with newly made observations (Heritage 1984; Glaser & Strauss 1967). To compare initial results ethnographic action researchers can, for example, discuss their preliminary findings with members of the project team and with other AEC professionals. In summary, ethnographic fieldwork can help to answer the question of which decision making processes a decision support system should address and which of the decision making processes the project team members can handle better without the support of a system during the observational part of action research (Randall et al. 2007: p. 4).

Figure 4-1 shows the ethnographic action research process to develop decision support systems. At the start of the iterative loop, ethnographic action researchers observe decision making routines and their required data models on a project using ethnographic research methodologies. By discussing their observations with the practitioners on the project, ethnographic action researchers can identify decision making routines that a system can support. Ethnographic action researchers then program systems that support those routines. Consecutively, the project team together with the ethnographic action researchers implement these developed decision support systems on the case project. Finally, ethnographic action researchers and project team members engage in another iteration of observations, analyses, development and implementation to validate or further improve the developed systems or to find a solution to support another of the project's decision making routines.

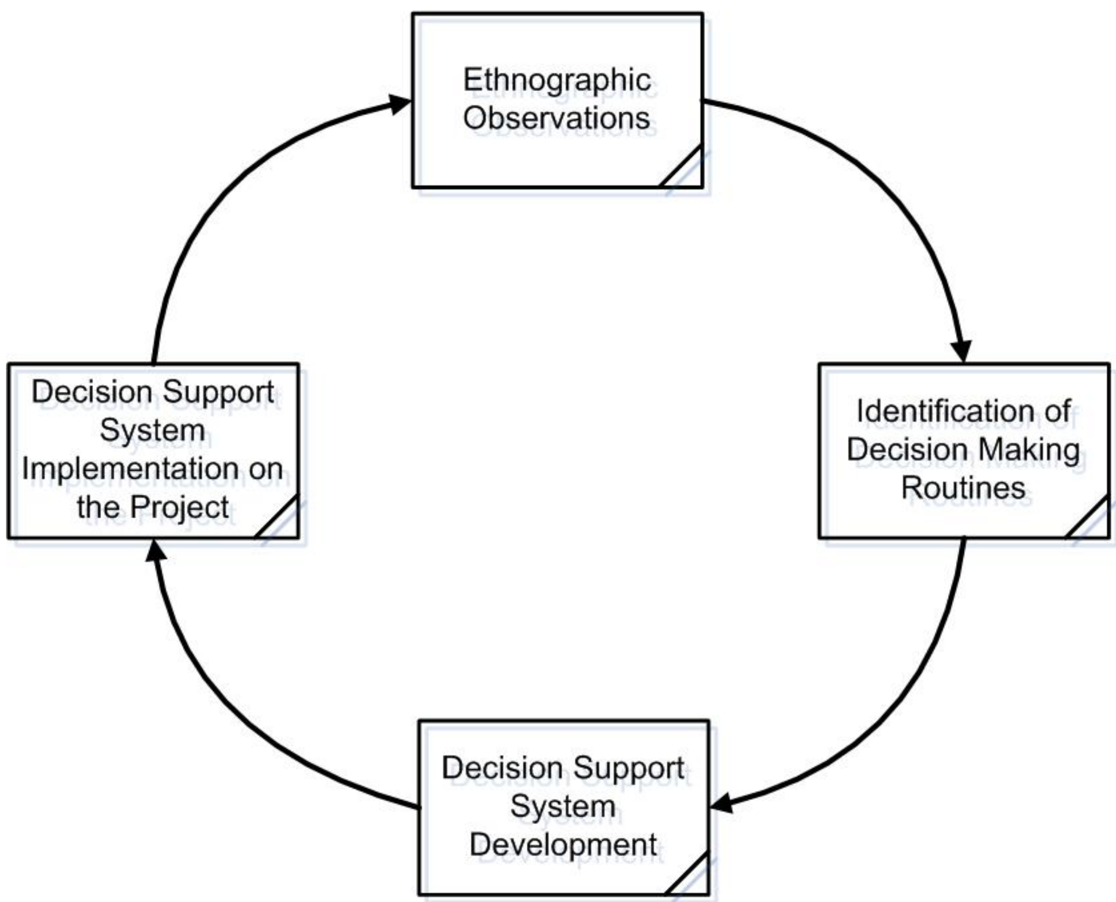

Figure 4-1 - Ethnographic Action Research Cycle for the Development of a Decision Support System

Summarizing, we propose that technology developers use the ethnographic action research approaches to effectively support project teams with developing and implementing decision support systems. In detail we propose the following:

- Using the ethnographic action research methodology, technology developers can develop an in-depth understanding about local project routines.
- Using the ethnographic action research methodology, technology developers can develop an enhanced understanding of the complex problems that practitioners face during their daily decision making tasks and, thus, of the tacit knowledge that practitioners need for these tasks.
- Due to the iterative nature of ethnographic action research, researchers can account for how practitioners change decision making routines to react to the frequent changes that occur on projects.

In the next section, we provide evidence for the validity of our propositions from observations from projects that applied the ethnographic action research methodology in practice.

4.7 Decision Support System Development with Ethnographic Action Research

This section traces two cases of the application of the ethnographic action research methodology on four real world AEC projects that we supported with ethnographic action research. The first case describes a longitudinal application of ethnographic action research on one project for the period of one year (the first author of the paper was the leading ethnographic action researcher on this project). On this project, we applied several ethnographic action research cycles to improve the decision making routines for a specific product and production management process. As we did not have a formal understanding of ethnographic action research when we started the effort on this project, we supported this project using the methodology unintentionally. Looking back, however, we unintentionally used the formal methodology that Randall et al. (2007) describe, and our reflections from the work on this project helped us to formalize the application of ethnographic action research on other projects. The second case describes a cross-sectional application of the methodology on three different projects that shows that iterations of the ethnographic action research cycles can be conducted on a number of different projects by different ethnographic action researchers. We collected data from the projects using multiple data collection methods, such as interviews, observations, and archival sources (Yin 2003). Additionally, as we conducted

Project 1	
Description	A large subway reconstruction project
Product and Production Management Process Supported	4D Constructability Review
Ethnographic Action Research Team	1 Ph.D. student 6 Project team members 2 Employees of the 4D software company
Cultural Characteristics	Distributed 3D modeling among several 3D modelers Contractually defined design submission cycles Different project team members used different location specific 4D models
System Development	Database to manage 3D model versions Database to manage 4D links between 3D objects and schedule activities Functionality to work with multiple 3D model files within 4D application
Project 2	
Description	Large hospital construction in California
Product and Production Management Process Supported	MEP Coordination
Ethnographic Action Research Team	3 Project team members 2 Technology managers of one of the AEC firms
Cultural Characteristics	Co-location of all stakeholders responsible for the MEP coordination
System Development	Two platforms to coordinate 3D modeling efforts of the various stakeholders MEP conflict resolution
Project 3	
Description	Large hospital reconstruction in California
Product and Production Management Process Supported	MEP Coordination
Ethnographic Action Research Team	1 Ph.D. Student 2 Project Team Members 1 Technology Manager of one of the AEC Firms
Cultural Characteristics	Geographically dispersed stakeholders
System Development	Internet-based ECPIP platform to help coordinate the 3D modeling efforts Conflict reports with snapshots of the conflicts to minimize the needed communication during the resolution of clashes
Project 4	
Description	Large sport stadium construction in Eastern Europe
Product and Production Management Process Supported	MEP Coordination Cost Estimating
Ethnographic Action Research Team	1 Ph.D. Student 3 Technology Managers of one of the Construction Firms 2 Project Team Members
Cultural Characteristics	Public project in Eastern Europe vs. private project in the USA Stadium vs. hospital
System Development (ongoing)	Integration of platforms to manage 3D modeling efforts and conflict resolution Automated quantity take-off to support the cost estimation of key cost indicators for sport stadiums

Table 4-1 - Summary of the test case projects

participant research our personal experiences while supporting the projects served as an important source of information (Jorgenson 1989:93). We analyzed the data using Eisenhardt's (1989) process of building theory from case studies and Miles and Huberman's (1994) methodologies to analyze qualitative data by triangulation of different data types. The four cases are summarized in Table 4-1.

4.7.1 Decision Support Systems to Support Construction Sequencing

Our first case project is characterized by a highly complex objective: to connect seven subway lines underground to enable passengers to transfer easily between the trains of each of the lines and to construct an above ground transit hub to serve a highly congested metropolitan area. As a closure of the affected subway lines during construction was not a feasible option, one of the project's constraints was to maintain all subway stations operational at all times while performing the necessary construction work. Due to the complexity of this constraint - some of the subway stations serve more than 200,000 passengers a day - the construction management team decided to use a 4D system to evaluate how to best sequence the construction work without interrupting the ongoing subway traffic. Such 4D systems allow AEC professionals to link digital three dimensional (3D) models of the project with construction schedules and visually simulate the construction sequences in the computer before they are built on site (Heesom & Mahdjoubi 2004; Koo & Fischer 2000). The implementation of the 4D system on this project has been reported in a number of publications (Hartmann & Fischer 2007; Hartmann et al. 2007).

The application of the 4D system posed a large challenge for the project team with respect to information management. To simulate the construction sequences the project team needed to create a three-dimensional computer model of the existing conditions of the project site and the proposed conditions from the submitted design drawings of the architects and engineers. Overall, the project team created 3D models representing more than 2,000,000 different building components that were stored in 228 different 3D model files. The project team then used the 4D system to link the building components in the 3D models to activities of a number of construction schedules, such as the master schedule of the client agency, or the schedules of the various contractors of the project that were responsible for conducting the construction work.

After a number of months of initial ethnographic observations on the project the researchers noticed a problem that persistently reoccurred and hindered the effective support of decision making tasks with the system. Due to the contractual routines on this project -

the project team modeled the 3D models from the 2D drawings that the design company of the project submitted in contractually required design submission cycles - the 3D models often did not represent the latest design submissions. Therefore, the members of the project team needed to understand which of the design submissions the respective 3D model represented to account for the version of the design during their decision making. However, there was no formal mechanism for the project team members to determine which of the design versions the 3D models were representing, and thus the members had to constantly compare the contents of the 3D models with the different 2D drawings of the various design submissions. As this task was very cumbersome and time consuming, this problem crystallized to one of the major technological barriers to applying the 4D system to support decision making under the local project conditions.

After analyzing the observed problem the ethnographic action researcher developed a solution to manage the relations between 3D models and 2D design drawings. He implemented a database that stores an entry for each revision of the 3D model files with fields for the date of the 2D design submission that the 3D model is based on, the name of the responsible 3D modeler, and the date when the modeler changed the 3D model. To enable easy access to the database for the 3D modelers and to enable the other project team members to easily access the database and get information about the respective 2D design version a 3D model was based on, the ethnographic action researchers additionally implemented a graphical user interface. Finally, the ethnographic action researcher unintentionally followed the ethnographic action research cycle by implementing the database right away on the project.

After the introduction of the version tracking database, the ethnographic action researchers realized another problem specific to the local routines of the project. On the project the construction management team had established routines of creating a large number of 3D modeling files, to distribute the modeling work among a number of different 3D modelers. However, in the past, on other projects that applied the 4D software application that was used on the project, the project teams had decided to store the 3D model within a small number of 3D model files. Thus, the 4D software was designed for the use with a small number of 3D model files. Therefore, working with a large number of files was very time consuming for the engineers on the project. Additionally, the 4D application stored the links between 3D objects and scheduled activities in the particular 4D model file. However, in addition to enabling multiple modelers to work on the project, another intention of splitting up the overall 3D model into so many small 3D model files was to enable the construction management team to create different 4D models to support decision making tasks for specific parts of the site. Often, the project team required the 4D simulation of parts of the project that were contained in different 4D files that had been previously created by a project team member. With the existing functionality of the 4D application the project team used, it was not possible to combine parts of two 4D files into a new 4D model. Thus, when creating a new 4D model, a project team member had to again manually re-link the required 3D geometry with the required schedule activities even if some of those links already existed in other 4D models. As the number of 4D models grew on the project - each based on a different subset of all the 3D model files and schedules - it also became increasingly cumbersome to maintain these 4D models as the underlying 3D models and schedules changed.

Again, the ethnographic action researchers analyzed the problem resulting from the specific project organization and started to develop a solution. He contacted the 4D software company which offered the ethnographic action researchers access to their source code. The ethnographic action researchers implemented the functionality needed to import a large number of 3D files seamlessly. Furthermore, ethnographic action researchers implemented a database to store the respective links between 3D objects and schedule activities external to the 4D model files. He additionally developed functionality in the 4D software to import the 3D object-schedule activity links into the database and export links appropriate for a specific set of 3D objects and activities from the database into the 4D application. In this way project team members were able to use 3D object-schedule activity links that had already been generated for other parts of the project to generate new 4D models. Again this functionality was introduced immediately on the project and it improved the project team's ability to support their decision making tasks with the 4D system significantly.

4.7.2 Decision Support Systems to support the Coordination of Building System Design and Construction

Researchers and practitioners see the improvement of the design and construction of MEP systems as one of the major opportunities to enable AEC projects to build facilities faster at lesser cost. They have this believe mainly because MEP systems account for about 40-60% of the total construction costs of a project and have become increasingly complex in the last couple of years (Khanzode et al. 2006a). One of the major issues with respect to the design and installation of MEP systems is that usually different contractors are responsible for the design of the different systems yet their design and construction are highly intertwined. Therefore, it is very challenging to coordinate the different contractors and integrate the different system designs to avoid possible conflicts during system installation.

Traditionally, practitioners manually overlay 2D drawings representing the various system designs to identify and resolve conflicts before contractors start to install the physical systems on site (Korman et al. 2003). Systems that use 3D CAD models to automatically check for interferences in the different system designs promise to improve this manual and cumbersome coordination process (Khanzode et al. 2006 a, b; Staub-French & Khanzode 2007). Furthermore, the use of 3D models enables the project participants to easily generate lists of quantities that estimators can use to estimate the cost of the project (Staub-French et al. 2003). However, the application of automated clash detection and quantity take-off produces a vast amount of additional information that needs to be managed by the project stakeholders. As the existing clash detection decision support system does not yet support information management processes within specific project contexts, automated clash detection decision support systems have not been applied widely in practice. This case describes how ethnographic-action researchers iteratively developed and implemented automated clash detection decision support systems on three projects: two hospital projects in California, and a sport stadium project in Eastern Europe.

On the first project, at the start of the effort, two technology managers of one of the project's companies got closely involved with the project team. They spent a number of days per week on the project, observing the MEP coordination work of the project team. Furthermore, they conducted a number of unstructured interviews and intensively discussed issues with current processes that the researchers identified. An analysis of the this ethnographic data showed that the project team solved most of the problems with respect to the exchange of information and the management of the building systems by co-locating all the different parties into one office space. The data showed that most of the required coordination occurred directly between the different stakeholders without the need to support integrated decision making with a decision support system. Therefore, the action researchers concluded that, contrary to their initial believes, the project team did not need much support with managing the ongoing collaboration of the project participants. However, the analysis of ethnographic data also showed that the coordination of the 3D modeling effort on this project and the management of the resolution of conflicts posed problems for the project team. Often different team members did not generate required 3D models or resolved conflicts in a timely manner which delayed decisions of other stakeholders. Therefore, the ethnographic action researchers developed and implemented a coordination management system that was accessible by all project stakeholders. The system supported the project stakeholders in managing the timely 3D model delivery to run the automated clash detection for specific project parts. Furthermore, the ethnographic action researchers supported the conflict resolution by developing and implementing a system to track responsibilities for resolving the conflicts. The results of the ethnographic action research efforts on this project are published by Khanzode et al. (2006a,b; Staub-French & Khanzode 2007).

Similar to the first project, on the second project an ethnographic action researcher, this time a Ph.D. student together with a technology manager of one of the project team's companies, got involved who closely observed the project team's work. The researcher traveled to the project every second week and spend two to three days with the project team. He observed the work of the team and conducted a number of informal interviews with the team members. Additionally, the researcher collected all available documents about the construction project, like for example, schedules, meeting minutes, or construction drawings. An ethnographic analysis of the data showed that it was not possible to simply introduce the technologies and processes that the ethnographic action researchers had developed on the first project. The analysis of the ethnographic data showed that due to the contractual relations on this project the project team was not able to co-locate all the MEP system contractors locally in one office. The ethnographic action researchers started to implement processes and technologies that could support collaborative decision making of all the stakeholders. The ethnographic action researchers developed an Internet-based decision support system to distributive manage the 3D modeling of the overall MEP system. The system also supported the management of the different versions of the submitted 3D models and the management of the different stakeholders responsible for the submissions. Consecutively, the ethnographic action researchers supported the project stakeholders in developing procedures to use the platform in another ethnographic action research cycle. Furthermore, the ethnographic action researchers on this project realized that managing the coordination of clashes by using a simple list of clashes posed problems for the practitioners as direct communication was limited due to the geographically dispersed stakeholders. Thus, it was important for all stakeholders to be able to identify the physical positions of the clashes within the 3D models easily during their clash resolution efforts. Therefore, the ethnographic action researchers developed an export of 3D model snapshots from the clash detection software into an issue list.

On the third project, a sport stadium construction in Eastern Europe, ethnographic action research efforts are still ongoing. An ethnographic action research team of two technology managers of the project team's company and one Ph.D student have finalized a first round of ethnographic interviews with project team members. Analyzing the interview data to understand the project teams work routines, the ethnographic action researchers have found two areas where a decision support system can support this project's project and product management processes. First, an analysis of the interviews showed that it is important for the project managers to resolve all the conflicts that they are responsible for before they submit a new version of the 3D model for another cycle of conflict detection. Therefore, the ethnographic action researchers have concluded that a product management system that supports the integrated management of the 3D models, the 3D modeling schedule, and the issues in existing versions of the 3D models will support the project team. Furthermore, on this project the analysis of the ethnographic interviews showed that several of the project managers could be supported with the important task of estimating the costs of the MEP installation. Thus, the ethnographic action researchers concluded that a project management system that automatically extracts key quantities from the 3D models will be helpful to support the project management routines on this project. Such a system would enable project team members to estimate whether the submitted design alternatives of the MEP contractors are within the project budget. At the moment of writing this paper, the ethnographic action researchers have started to develop a decision support system that can support these identified project routines. In a next step, following the ethnographic action research cycle, they plan to implement the systems on the project. .

4.8 Implications

The findings from the longitudinal and the cross-sectional cases show that the ethnographic action research methodology worked well to identify problems AEC practitioners face with specific product and production management decision making routines, and to react to changes in the requirements of decision support systems. In both instances the researchers were able to identify complex problems that practitioners faced during their day to day decision making tasks using the ethnographic action research method. For example, on the first case the researcher realized that project managers need to be aware of the respective version of 2D design documents the 3D models are based upon to be able to use the 4D system to make decisions. In the MEP coordination cases, the ethnographic action researchers identified, for example, that the management of the 3D modeling effort and the coordination of the resolution of identified conflicts posed problems during the decision making tasks of the engineers. Furthermore, both cases show that the ethnographic action researchers gained insights about the various decision making routines on the projects with ethnographic observations and by conducting ethnographic interviews. On the first case, for example, the ethnographic action researchers recognized quickly that the project team on this project worked with a large number of different 3D model files, an approach that had not been previously considered by the 4D software vendor company, but was beneficial to support local routines on this project. Thus, even though a number of projects had used the 4D software successful previously, on this project, without the intervention of the ethnographic action researchers, it would probably not have been possible to close the gap between the potential benefits of the 4D system and how it could be objectively used on the project. Therefore, it would have been most likely that the practitioners would have declared 4D modeling as not useful to support their work. The MEP coordination cases show how the methodology helped to provide insights into the decision making routines of the three different projects and highlighted the possibility for the ethnographic action researchers to custom-tailor decision support system solutions that supported each of the respective project environments. The MEP coordination cases also show how the ethnographic action researchers were able to understand differences of how practitioners make decisions across a number of projects. For example, on the second project in the MEP coordination case, the ethnographic action researchers realized that practitioners started to understand conflicts directly within the 3D models and no longer used 2D drawings. The ethnographic action researchers reacted to this change in the working habits by providing 3D model snapshots of clashes that enabled the easy location of conflicts within 3D models. In summary, the findings from our cases show that by using the ethnographic action research methodology it was possible for the ethnographic action researchers to integrate decision support systems closely with the requirements on the local projects. In this way it was possible to reduce the gap between the potential benefits that the decision support systems promised for the project and the technical reality of how well the systems supported local project decision making routines in detail. This reduced gap, in turn, led to a higher acceptance of the decision support systems among the project team members and in the end the system was applied successfully on the projects to support decision making routines. Additionally, ethnographic action researchers were able to react to different project contexts and to changes on single projects.

The findings on our cases also provide evidence that Latour's (1987:107) claim that the traditional product management life-cycle of invention-development-implementation does not work well also holds for the development of decision support systems for AEC projects. The findings on our case studies show that to support the projects with a decision support system that the project participants can use and integrate seamlessly into their decision making routines, a clear distinction between the invention, the development, and the implementation of the decision support system is not possible. The iterative adjustment of the system to the respective project routines was necessary which blurred the boundaries between the stages. This finding might provide another explanation for the existence of the large gap between the potential benefits of previously developed commercial decision support systems and their ability to support local AEC decision making routines with them. The observations from the projects show that the ethnographic action research model is a feasible alternative to develop decision support system for the AEC industry.

Overall, the findings from the cases show that ethnographic action research can work well for the development of decision support systems within the AEC industry. Thus they complement existing theory about ethnographic and action research methodologies. One of the major criticisms to the ethnographic research methodology for supporting systems design is that its applicability is mainly shown for relatively well-defined computer-supported cooperative work (CSCW), such as control rooms for airport or underground traffic control. So far, few researchers have tried to identify for which settings the methodology is appropriate and for which settings it is not (Iqbal et al. 2005; Randall et al. 2007:7). This paper shows that ethnographic action research is appropriate to develop decision support systems within the ill-defined, more complex settings of AEC projects. Another common critique is that ethnographic action research is limited to the development of relatively small systems and that the methodology is time intensive (Randall et al.:4). The findings on our cases show, however, that with the small iterative ethnographic action research improvement cycles the research subjects can be almost immediately supported by the research results. In this way the subjects of the ethnographic observations can quickly profit from productivity gains and the significant costs of the application of the ethnographic methodology can be counteracted.

From an academic standpoint ethnographic research and action research methodologies make it hard for researchers to develop general and theoretical constructs that can differentiate the results of the ethnographic action research from consultancy work (Baskerville & Wood-Harper 1996). Eden and Huxham (1996) identified a number of requirements so that ethnographic action research can be considered as qualitative research. Table 4-2 argues that all these requirements are fulfilled for the ethnographic research of the cases. Summarizing because the research efforts were grounded in previously published research (Heesom & Mahdjoubi 2004; Koo & Fischer 2000; Korman et al. 2003) and because we used generally accepted research methodologies on the cases (Eisenhardt 1989; Miles & Huberman 1994; Yin 2003), we consider the application of the research methodology on the cases as qualitative research. In this way, we provide evidence hat the ethnographic research methodology can additionally inform decision support system research and is not only system development or consulting activity without any generalizability of the outcomes. While we agree that ethnographic or action research cannot typically produce research results that are general to a great extent, we believe that it is important for researchers in the AEC industry to realize that due to the complex and changing character of the industry it is overall challenging for researchers to develop generalized research results with any research methodology. Therefore, ethnographic action research might actually be a good approach to generalize constructs through the iterative application of research findings from one project on a number of other projects as we showed with the MEP coordination case.

Requirement	Argument to justify the validity of the case research
• Ethnographic action research must have implications beyond the domain of the projects. • Ethnographic action research demands an explicit concern with theory. • The basis for designing tools, techniques, models, and methods must be explicitly shown and related to theory. • Ethnographic action research will develop emergent theory. • Theory building will be incremental, moving from particular to general in small steps. • The presenters of ethnographic action research must be clear what they expect the consumer to take from it and present the findings of the ethnographic action research with a form and style appropriate to this aim. • The result of detecting the emergent theories must be demonstrable through argument and analysis.	The ethnographic action research on the first project shows how the constructability review on AEC projects can be supported with decision support systems. The generalized findings have been published in a peer-reviewed journal paper (Hartmann & Fischer 2007). The research approach has been based on previous theory (Heesom & Mahdjoubi 2004; Koo & Fischer 2000), and the findings complement this theory. The case of the MEP coordination shows how ethnographic action researchers used results from one project to inform the routines of other projects and thus provides evidence that ethnographic action researchers can generalize the findings published for the first project (Khanzode 2006 a,b) for the use on other projects. Additionally, ethnographic action researchers again consulted and extended previously developed theories about MEP coordination (Korman et al. 2003). Also, the results have been published in a peer reviewed journal paper (Staub-French & Khanzode 2007).
• A high degree of method and orderliness is required in reflecting about the emergent research. • The possibilities of triangulation should be fully exploited. • The history and context for the intervention must be taken as critically.	On both cases, generally accepted qualitative research methodologies have been applied (Eisenhardt 1989; Miles & Huberman 1994; Yin 2003) that suggest an orderly theory development process (Eisenhardt 1989), triangulation of data (Miles & Huberman 1994; Yin 2003), and considerations of history and context (Eisenhardt 1989; Miles & Huberman 1994).
• The data collection process should focus on aspects that cannot be easily identified by other methods.	As there is little room for experimentation with different ECPIP designs during the short life-time of a project, the developed ECPIPs need to be right the first time around. Ethnographic research supports the development of technologies in such environments (Randall et al. 2007:19). We suspect that other research and data collection methodologies would not have worked well in the contexts we present in this paper and found on many AEC projects.

Table 4-2: Summary of the test case projects

4.9 Limitations, Boundary Conditions, and Outlook

This paper provides evidence that the ethnographic action research methodology works well for the development of decision support systems to support AEC projects. In other contexts it might be appropriate to use different methods. For example, the methodology might not work well for the development of technologies that require a more profound computer science or engineering informatics background then the decision support systems we present in this paper, such as CAD applications or finite element software. However, other researchers have shown the applicability of iterative development methodologies for complicated decision support systems to support decision making, by for example, computing project cost probabilities (Raphael et al. 2007). Another problem of our research is that ethnographers that wish to inform system design need to take the standpoint of one group of actors within an organization (Becker 1967; Randall et al. 2007:39). As we focused on one level of analysis - the project team - in this paper, ethnographic action research, as we present it here, does not reflect the requirements for other actors, such as, upper management. To develop systems that satisfy the needs of the different stakeholders an analysis of the different stakeholder viewpoints is necessary (Lim & Sato 2006). How such a viewpoint analysis integrates into the ethnographic action research methodology needs to be addressed by future research.

Our findings on the cases point out a number of other limitations and boundary conditions of the ethnographic action research methodology. Two inherent problems occur at the intersection between ethnographic research and action research. It was often not easy for the researchers to identify the right moment of when to convert the findings from the ethnographic observations into implemented software. The point of time of a technology intervention on projects is a sensitive issue (Carroll 200:12). If ethnographic action researchers intervene too early with the introduction of an iteratively improved version of the system, the project stakeholders are often not able to readily apply the new version as the ethnographic action researchers have not yet observed important requirements that must be met to support the project team members. On the other hand, if the ethnographic action researchers intervene too late, valuable time is lost, both to improve the product and production management decision processes of the practitioners and to make valuable observations of how practitioners apply the new version of the decision support system. The second problem is that - especially if multiple ethnographic action researchers are involved in a research effort - the results and reports of ethnographic research efforts lack consistency and are often incomplete. Therefore, the ethnographic action researchers on the cases often struggled with translating the findings of their observations into the analytical model representations that are required to program decision support systems. Models of how to translate a narrative scenario description into a formal model description are poised to help during these translation efforts (Haymaker et al. 2004; Sato 2004). How ethnographic action researchers can integrate these models into the ethnographic action research methodology, however, remains an open problem for future research efforts.

Another limitation of the presented methodology is its iterative character. Researchers, technology managers, and technology developers alike are usually evaluated by the immediate magnitude of the success of an implemented software system. It may be hard for each of these parties to justify the slow and piecemeal improvement process of the ethnographic action research methodology. All participants in ethnographic action research efforts have to understand that there will not be immediate and significant changes in the decision making processes and productivity, but, that changes are slow and continuous.

Additionally, ethnographic action research needs to overcome the resistance of possible system users to use the system during their daily work. Resistance to use has been cited as one of the major impediments to the successful implementation of technology (Rani et al. 2007). The ethnographic action research methodology will only work if the practitioners overcome their resistance and work closely together with the ethnographic action researcher. To overcome this resistance is also one of the important factors for a sustainable success of the technology implementation after the ethnographic action researchers have left the project. If projects cannot overcome the resistance of their members to use a decision support system, the use of the system often stops after the ethnographic action researcher, who may have been driving the system implementation as a champion, leaves the project. However, the iterative character of the ethnographic action research methodology can also improve the willingness of system users to apply the system in their daily work. The method helps to slowly close possible competency gaps (Levitt & March 1988) between existing decision making routines and new decision routines supported by systems. The method helps as the learning steps that the practitioners have to take to be able to use the system are smaller and as they realize that ethnographic action researchers make the adjustments necessary to fit the technology to the local project routines.

A final limitation of the ethnographic action research methodology to develop decision support system solutions for the AEC industry is that new software development technologies and ways to manage software development approaches need to be applied that support a constant and iterative improvement of existing tools. Fortunately, in the last couple of years, such software tools have been developed. From a development technology standpoint asynchronous JavaScript and XML (AJAX) seems to be poised to support ethnographic action research well. AJAX applications reside on centralized servers and use browser capabilities on client machines as user interfaces to the applications' functionalities (Garrett 2005). This approach enables the central storage of all the application logic and data on a server. In this way, new versions of the applications can be updated quickly without the need to ship the new release to all users and the need for the users to reinstall applications locally. Furthermore, AJAX applications support the centralized storage of information and thus support collaborative work on AEC projects well. From a technology management standpoint, one of the main problems of the ethnographic action research approach is to make decision support systems that have been developed for one project available to other projects that intend to use parts of the previously developed functionality or plan to extend the functionality. To support such an ongoing exchange of decision support systems between projects the traditional software delivery model does not work well. It is, for example, rare that software companies provide their source code to ethnographic action researchers as it happened on one of the case projects. Thus, it is most likely that a successful and widespread application of the ethnographic research methodology will need to be supported by Open Source projects (Von Hippel & von Krogh 2003). In the long run, we envision that a vibrant Open Source AEC community could emerge that uses the ethnographic action research methodology, develops decision support system to support various product and production decision making processes in AJAX that are capable of improving the productivity on AEC projects, and shares these decision support systems with other projects world-wide.

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5 Appendix – Data Inventory

This appendix presents an inventory of qualitative data I collected during my field work. The inventory lists types and amount of data and briefly describes how I used the data to arrive at the research results I presented in chapter two of this thesis. As mentioned in chapter two, I did not follow more standardized qualitative research coding techniques because of the inconsistency of the data that was caused by the constant redefinition of the research questions during the field work.

		Fashion Setter's Influence	Experienced PM's Influence	Spirit of the System	Gap between Spirit and Technical Reality	Opportunity and Control	Utilization
Construct Development	Field Notes	X	X	X	X	X	X
	4D Use Diary				X		X
	Lessons Learned Diary	X	X	X	X	X	X
	Publications and Reports	X	X	X	X	X	X
Triangulation	Electronic Communications	X	X	X	X	X	X
	Meeting Minutes	X	X	X	X	X	X
	Presentations			X	X		X
	3D/4D Models				X		X
	3D Change Database						X
	Other Documents	X	X	X	X	X	X

Table 5-1 - Summary of Data Sources and how I used them during data analysis

Table 5-1 summarizes how I used different data sources during my theory development to arrive at the constructs presented in chapter two. The table also shows that I used two different kinds of data sources. First, I used documents that I created by myself that recorded my observations and ongoing analysis efforts. These documents especially helped me to develop the constructs presented in chapter two. In this way, these documents served as an adequate substitution for formal data coding techniques (Jorgenson 1989:105). These documents include my field notes, two different kinds of diaries, and a number of evolving report drafts. The second kind of data is project specific accounts of project managers. I collected the electronic communications of the project managers, the 4D models that the project team created, construction drawings, presentations, meeting minutes, meeting participation lists, records within a 3D model change database, and a number of selected other documents. I used these documents to triangulate the constructs that I developed from my observations on the project. In this way, I was able to specifically control whether my observations and the analysis of my observations reflected the occurrences on the project. In the rest of this appendix I will in detail introduce each of the different data sources and briefly describe how I used them during data analysis to arrive at the constructs presented in chapter two.

5.1 Field Notes

Figure 5-1 - Example of two pages from my field notes

Throughout my fieldwork I recorded field notes in letter sized notebooks. These field notes were one of the main sources of information during the development of all of the theoretical constructs. The notes are in scratch format; I created short notes of events that I deemed important, often using bullets. These short notes then helped me to refresh my memory when I started to summarize and analyze my observations in the more formal diaries and reports. Figure 5-1 shows an example of a page of my scratch notes. At first glance, these notes are probably unintelligible to anyone but the writer, but in hindsight these notes proved to be of exceptional importance during the analysis and development of the more formal reports because they allowed me to reconstruct project events. The field notes were helpful during the development of all the constructs presented in chapter two and served as a basis to generate the two different kinds of diaries and the draft research reports.

5.2 4D Use Diary

Throughout the direct participant observation on the project I kept a diary of all uses of the 4D system that I observed. Each entry in the diary resulted from a reflection about the field notes. Overall the diary contains about 40 different entries about 4D model uses. This diary helped me to identify when and how the project team members used the 4D system for decision making and other tasks. In this way, the diary was helpful to develop the constructs of the gap between the rhetoric and the reality and how the project team utilized the 4D system throughout the different phases of the project. The following excerpt shows an example of the diary:

PA – [some subway] entrance

> **Design change in an adjacent [client agency's] project causes a design change in [this project]. [The design company] needs to design a new column layout that facilitates passenger flow. 4D model used to create several avi-walk through and still images. (10-7-04)**

[some subway line] – secant pile walls on both sides necessary?

> **Do there has to be weight on top of the tubes due to elastic deformation? (10-27-04)**
>
> **Dewatering vs. Tiedown issue (10-27-04)**

[some subway line] – temporal road deck

> **street thickness over [a] street (10-27-04)**
>
> **size of temporal beams: why W36 (10-27-04)**

Transit center foundation East Secant Pile Wall– underpinning of adjacent building's wall necessary? (10-20-04)

Transit Center – [some subway line] Passenger Routing and Logistics Evaluation of possible passenger routes during construction. (10-26-04)

5.3 Lessons Learned Diary

In addition to the diary that tracked how the CCM team used the model, I also kept a diary that recorded my thoughts on what I learned about the use of the models on the project. This diary helped me during data analysis to develop all the constructs presented in chapter two. Especially, however, the lessons learned diary was very useful analyzing the technical reality at specific points in time. Below is an excerpt from this diary:

<u>Linking the Deconstruction Schedule:</u>

<u>Request for 4D model:</u>

[The Project Manager] wanted to evaluate the deconstruction schedule of the Transit Center Site (Buildings: 196 [a Street], 198 [a Street], 200 [a Street], 204 [a Street])

<u>Initial Problems:</u>

4D Management Team was not aware that the schedule already contained a detailed level by level deconstruction schedule. This was either due to the fact that the latest Master Schedule was not made available in time for the 4D team or that the available schedule were not submitted within the needed level of detail, e.g. the hammock activities that break up the deconstruction, hazmat removal etc. were not included.

<u>Approach:</u>

[The scheduler] refined the existing schedule, splitting up the deconstruction for each level into the tasks for "Relocate Tenants", "Remove Hazmat" and "Deconstruction". This schedule was then submitted as a stand alone version, e.g. containing only the deconstruction activities, to the 4D team. The 4D team created a [4D application] model, only importing the geometry needed for linking and visualizing the scheduling sequence.

<u>Linking the model:</u>

One main distraction within the schedule was that the numbering of the levels of the buildings started with the first basement level. Thus the physical first level of the building (level at street) was numbered differently, e.g. for a building with two basements the level was called "level 3". This confusion was

resolved by calling the scheduler […]. Also the 4D team needed to adjust the model slightly. The 3D modeler […] did not split up the basements into different levels. The remodeling was carried on by [the 4D Specialist]. Also an error was introduced linking the model as two of the buildings within the schedule were exchanged and thus the schedule activity was linked to the wrong building. The process of creating the 4D model including remodeling, geometry regrouping and linking took approximately 4 hours.

<u>First Analysis of the Model:</u>

The first analysis of the model was executed by [the Project Manager] and [the 4D Specialist] on Jan-24. A slight schedule inconsistency was found. The Tenants of one of the buildings were relocated while the adjacent building was deconstructed. This would lead to an unnecessary risk for the tenants to relocate. It was thus decided to revise the schedule accordingly.

<u>Outlook:</u>

It was decided that the schedule was to be revised by [the Scheduler] and the updated version sent to [the 4D Specialist] for re-linking the model.

5.4 Research Reports

I constantly worked on a number of evolving drafts of research reports about problems that I thought were most important at that time. These drafts, especially, at the beginning did not address the problem that I finally addressed in my thesis. However, they helped me in focusing and recording my observations. It turned out that the drafts were an important contribution during the development of the theoretical constructs as they spelled out the prevailing problems at different times on the project. Examples, of draft research reports are:

- A start of a paper addressing the problem that projects do not start creating 3D models with the idea to use them for various tasks. This was mainly a reaction to the problem at the start of the project that we were not able to use the previously created 3D models of the design company. As described in chapter two this problem delayed the successful start of the 4D system use.
- A draft paper addressing the challenges to manage 3D modeling efforts for construction projects. This draft resulted in a rejected CIFE seed proposal. The draft also shows how my formulation of the observed problem shifted from product (3D modeling problems) to process issues during the modeling effort.
- A draft about the process of how to apply 3D/4D systems to support constructability review. The draft started with an early attempt by Martin Fischer and me to spell out

how the project team could best apply the 4D system to a number of project issues. This draft finally evolved into the Building Research and Information paper.

- The summary of my work that I wrote in the week before I left the project. This draft resulted in a CIFE Technical Report and a number of company internal reports. The draft ended up to provide the framework for a paper that collects data from a large number of CIFE projects. The paper will be published in the Journal of Construction Engineering and Management.

Summarizing, these drafts resulted in the following formal publications:

Hartmann, T. and M. Fischer (2007). Supporting the Constructability Review with 3D/4D Models. Building Research & Information 35(1): 70-80.

Hartmann T. (2006). How to Set Up and Manage a 3D/4D Modeling Project. Published as an internal Technical Paper of one of the CCM team's joint venture companies.

Hartmann T. (2006). How to Present a 3D Model in 4D. Published as an internal Technical Paper of one of the CCM team's joint venture companies.

Hartmann T. (2006). How to Link and Present a 4D Model. Published as an internal Technical Paper of one of the CCM team's joint venture companies.

Hartmann, T., B. Goodrich, M. Fischer, and D. Eberhard (2005). CIFE Technical Report #170.

Hartmann T. and M. Fischer (2005). Developing Guidelines for 4D Modeling on Construction Projects. CIFE Seed Proposal 2005 (not funded)

5.5 Electronic Communications

The members of the CCM project team used Emails extensively to communicate. The team estimates that during the two years of data collection the CCM team sent and received around 100,000 Emails. Therefore, these Emails were a very valuable source of information about what happened on the project. During data analysis, I triangulate my constructs with around 100 Email conversations that were related to the 4D effort. In hindsight, the construct triangulation with Emails were my major data source in confirming the categories of control, opportunity, spirit, technical reality, fashion setting, and influence of experienced project managers that I observed during my fieldwork. Below is an example of one Email communication that is coded for occurrences of these theoretical constructs.

Re: [Project] 4D Modeling Challenge - IMMEDIATE Resolution Required
From: [Project Manager A]
To: [Fashion Setter D]; [Fashion Setter C]
Cc: [JV President]; [Project Director]; [Project Manager B]; [Fashion Setter I]; [Fashion Setter J]; [3D Modeler A]; [Office Engineer A]; [Fashion Setter K]
Sent: Thu May 25 4:16:05 2006

[Fashion Setter C]/ [Fashion Setter D],

I want to thank you for the suggesting to [Consulting Company A] that they consider engaging me at their most recent AEC Technologies 2006 conference to speak about What's Missing in BIM. The experience was positive, exposing myself and [my Company] to the director of [Consultant Company B] and many prospective collaborators (as well as competitors). In my opinion, each time [my Company] presents at functions such as these our value to the industry is recognized.

Spirit:
The ability of using a 4D model as a construction management tool is presented by the project managers of the team on conferences. (1)

However, in addition to thanking you for this opportunity, I also want to express my frustration with [my Company] as a BIM implementer. One of the few projects within [my Company] where BIM continues to be used as a construction management tool is the [Project]. Due to the financial support of the client (hundreds of thousands of dollars) and to the efforts of people like myself, [Office Engineer A], [Project Manager B], and [Project Director], this BIM has been kept

viable.

We had a major presentation today with the client. Once again, conversion of the model files to vrml files to be uploaded to [4D Application A] proved to be an insurmountable challenge. The client made it very clear today, if we are unable to show the value of a 4D model to the client by next Thursday, they will no longer provide monetary support for this effort.

This is now the third occasion when [4D Application A] has not performed, rendering the model impotent! We, at the [project's] field office, are unaware of who should be contacted from [4D Company A] to support our efforts. We have no one to assist with troubleshooting. We have been abandoned. This MUST be corrected within 3 days.

By Wednesday of next week the model MUST be linked to the schedule saved as an avi and distributed to the client displaying its prowess. You must provide the technical support we need. We have a 3D model. We have a schedule, and yet, we have no way to demonstrate how this 4D model works walking one through the virtual construction of this contract.

On Friday, June 2nd, the executive director of the Construction Management Association of America will be visiting the [my Company] in order to learn how [my Company] is making use of this new technological tool. I

Spirit:
The team attributes their problems with the conversion of 3D models to the software (2).

Technical Reality:
The team tried to use the 3D model on three occasions and failed (3).

Control:
Project Manager A feels that it needs somebody from outside to support them with their implementation, but does not know who to talk to (4).

Opportunity/Threat:
Project Manager A perceives the need to provide a working 4D model in 3 days (5).

recently participated on a panel at the [AEC] conference where the attendees were informed that BIM is the future and the future is now. If [my Company] wants to continue to tout our strength as leaders of this cutting edge technology we'd better rise to this challenge. I repeat we need to have a viable model streamlined with [4D Application A] in working order no later than Wednesday. This will allow us to perfect our work on Thursday and have an avi to distribute Thursday and a model to present to the CMAA Friday morning.

I look forward to certain action items taking place tomorrow with resolution w/in 3 business days.

Thanks.

[Project Manager A]

Re: [Project] 4D Modeling Challenge - IMMEDIATE Resolution Required
From: [Fashion Setter C]
To: [Project Manager A]; [Fashion Setter D]
Cc: [JV President]; [Project Director]; [Project Manager B]; [Fashion Setter I]; [Fashion Setter J]; [3D Modeler A]; [Office Engineer A]; [Fashion Setter K]; [Fashion Setter B]; [Fashion Setter A]; [Fashion Setter L]
Sent: Sent: Thu May 25 7:01:23 2006

Fashion Setting: Fashion Setter C tries to convince Project Manager A that the 3D Modeling Application was used successfully earlier (6).

[Project Manager A] & Co, I am surprised to

hear that you are having these issues at this stage of the game. I was led to believe that the [Project] team was successfully producing 4D Models using [3D Modeling Application A], [Scheduling Application A] and [4D Application A] both last year and this year. aren't you still working with the same people and processes ? What changed since then ? I was also under the impression that [Fashion Setter B] had successfully worked with the 3D modelers, Schedulers and Engineers to leave behind a working solution for the future. Again, did something change or did we never have the team adequately trained. Also, I paid for [Fashion Setter J] to shadow the project and learn [4D Application A] in the process. Did anyone ever contact [Fashion Setter J]? Why are we just now hearing about this ??

Utilization:
No one followed up on problems and the model was ignored by the project team for some time (7).

As for [4D Application A] support, did anyone from your project ever contact [4D Company A] support directly for troubleshooting or assistance ? There where questions of software maintenance and support earlier this year, but I thought those had been resolved. Did they not respond to you ? Did anyone ever follow-up or simply wait until now to raise these issues ?

As you know, we are currently using [4D Application B] for the [another project]'s 4D Modeling instead of [4D Application A]. A couple years ago, it was not a viable solution, but it has now become the preferred software solution for 4D Modeling across the

industry. (Technology moves quickly as you know)

I would like to help you if I can. I would suggest staying the [4D Application A] route if its simply a matter of having someone who can adequately operate the software. If there are different issues such as VRML compatibility, then we need to figure out who or what changed since we had this stuff previously working. We could conceivably develop a 4D Model in [4D Application B], but I don't know enough detail to make this call yet.

Feel free to call my cell phone tomorrow if you would like to discuss. I am hopeful that we can reach a solution that works in the short term as we try and determine what to do in the long term.

Thanks,
[Fashion Setter C]

Re: [Project] 4D Modeling Challenge - IMMEDIATE Resolution Required
From: [Project Manager A]
To: [Fashion Setter A] ; [Fashion Setter B]
CC: [Project Manager B]; [Office Engineer A]; [Fashion Setter C] ; [Fashion Setter D]
Sent: Fri May 26 05:12:32 2006

Sense-Making:
Project Manager A starts making sense of the situation: Conversion problems due to scaling and coordinate origins (8).

Some vrmls were posted yesterday. The problem which occurred had to do with scaling and non-coordinated origins….Any

suggestions are greatly appreciated.

[Project Manager A]

From: [Office Engineer A]
To: [Project Manager A]; [Fashion Setter B]
Cc: [Project Manager B]; [3D Modeler C]; [3D Modeler A]
Sent: Fri May 26 7:19:52 2006

[Project Manager A]

After the meeting yesterday [3D Modeler C] and myself talked with [3D Modeler A] (sp?) for a short time about the problems we had. [3D Modeler A] was fairly certain that the issue was not one with [4D Software A] but rather with converting the files properly. As a recap because I do not know the details of how CAD works, when working in one of the formats (3D Modeling Application C, 3D Modeling Application A, or 3D Modeling Application B) any drawings are stated at the origin so when they are converted the files have to be imported with the correct origin and scale. The conversation was then advanced when [3D Modeler A] explained that the way the conversions to vrml were supposed to be done, to reduce complications, was all at once. [3D Modeler C] was converting each working file one by one, how it was originally done was a new drawing was created with all the working files as references and then converted at once.

Sense Making:
Office Engineer A starts to make sense of the situation: The problem is not due to the [4D Application A], and all model files need to be converted at once (9).

I think the main issue we had yesterday was that [3D Modeler C] was not properly shown how organize and convert the model, and since [3D Modeler D] was out for the week she didn't have someone to confer with. I believe before [Fashion Setter B] left he had prepared a guide for the modelers to follow, am I correct [Fashion Setter B]? Yet even this would have been caught if we had more time to put everything together.

The only issues we have had strictly concerning [4D Application A] is: 1) trying to figure out where the licenses are for the full version, and for the newest version. And 2) Its tendency to crash and loose data, a month ago I lost half a day of work when common point froze despite frequent saving, and wednesday/thursday the file had reverted back to a previous version loosing my nights work.

[Office Engineer A]

Re: 4D Modeling
From: [Project Manager A]
To: [Office Engineer A]; [Fashion Setter B]
Cc: [Project Manager B]; [3D Modeler C]; [3D Modeler D]
Sent: Fri May 26 10:23:03 2006

If [3D Modeler C] can create proper vrmls and [Fashion Setter B] can help you, then by next

Thursday we should be able to distribute a complete avi to the client.Yes?

Sent from my BlackBerry Wireless Handheld

Re: 4D Modeling
From: [Office Engineer A]
To: [Project Manager A]; [Fashion Setter B]
Cc: [Project Manager B]; [3D Modeler C]; [3D Modeler D]
Sent: Fri May 26 7:52:51 2006

I think the following week would be more reasonable to get something usable if I got all the files early next week.

The last 4D model that has been successfully used was the original model that [Fashion Setter B] and I started and I linked and kept maintained and updated. That took a good deal of time to get to the point where it looked good and flowed well. Also that was at a time before [a part of the project] got underway and so got my full attention.

Opportunity/Threat:
Office Engineer believes that a successful use of the model is possible (11).

In moving forward to get the new model to that point again I would need the remaining existing drawings to be converted (because you may notice all that is shown is slabs), the schedule has to be broken down into greater detail because at this point each work zone has slightly more than demo structure, build structure, demo stair/ramp, build stair, and I would need a reasonable

timeline to get it done taking into consideration that everything dealing with [a Contract Package] moves through me.

Re: 4D Modeling
From: [Fashion Setter B]
To: [Office Engineer A]
Sent: Fri May 26 11:05:01 2006

[Office Engineer A] -
I can do some stuff this weekend. After all [your company] still pays some of my tuition.
Let me know...
[Fashion Setter B]

Re: FSTC 4D Modeling
From: [Office Engineer A]
To: [Fashion Setter B]
Sent: Fri May 26 1:20:32 2006

Thanks [Fashion Setter B] but I have to wait for the remainder of the files before I can start. Plus the design has changed so much and you are so far removed that it would probably be difficult for you to understand the phasing without the drawings and phasing plans. I will keep the offer in mind if anything comes up where we could use your help.

DSS/Project context: An example of how a Fashion Setter cannot enroll in the Technical Reality because he lacks local knowledge (12).

[Office Engineer A]

Guides

From: [Office Engineer A]
To: [Fashion Setter B]
Sent: Aug 01 2006 5:23:02 2006

I found your guides, they would not open properly on my computer, hopefully you have better luck on yours.

[Office Engineer A]

[4D Application B]
From: [Project Manager A]
To: [Fashion Setter C]; [Fashion Setter K]
Cc: [Project Director]; [Project Manager B]; [Office Engineer]

[The project] would like to officially purchase the software and begin to set up some training.

Please advise.

[Project Manager A]

Experienced Project Managers: Despites the opinion of the Office Engineer A that the problem is not one with the [4D Application A], Project Manager A is able to integrate her opinion into the spirit of the team. The [Project Director], [Project Manager A], and [Project Manager B] decide to purchase [4D Application B] (13).

5.6 3D and 4D Models

At the time I left the project (end of phase four, see Figure 2-1 in chapter two of this thesis), the CCM team had represented the overall 3D model in 228 different 3D model files. Altogether, these files contained 44,711 3D objects and 2,962,333 polygons. From a data analysis point of view, the 3D and 4D models helped me to assess two of the theoretical constructs of the grassroots model: Effective use for decision making and technical reality. The 3D models and the quantitative data of the model sizes also helped me in evaluating costs and budgets for the modeling effort.

To create 4D models for specific analysis purposes the CCM team linked these 3D models to two different kinds of construction schedules: the overall Master Schedule and the different schedules of subcontractors. The CCM team then applied these 4D models on a number of occasions. The 4D use diary tracked these model uses in detail and helped me to develop the constructs of technical reality and utilization. Additionally, however, I used the 4D models to triangulate the entries in the 4D use diary. The following examples of 3D/4D models show how various examples of how the 4D system was used to effectively supported decisions.

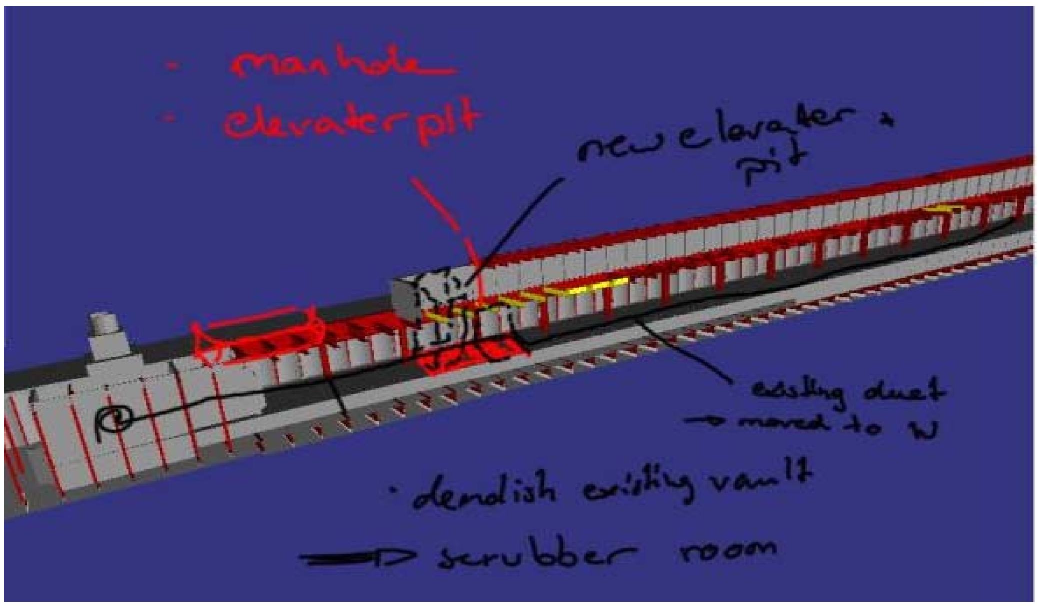

Figure 5-2 - The CCM team used this 4D model in a meeting to evaluate a change in one of the subway station's designs. In this meeting, for example, the 4D model helped the CCM team to decide that the client would need to acquire one of the adjacent building vaults to build a scrubber room.

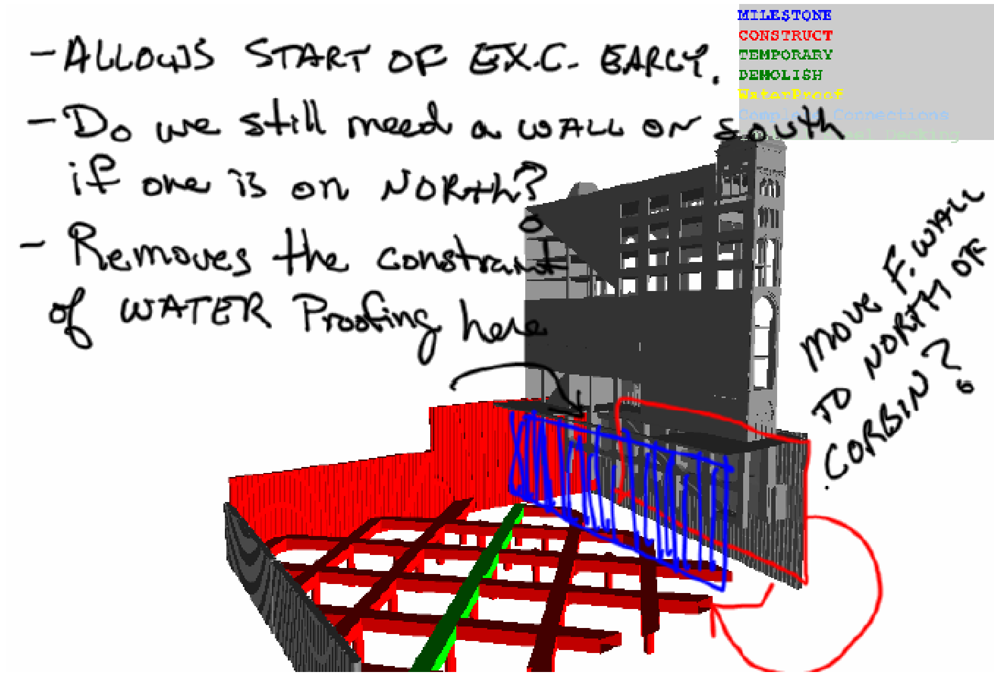

Figure 5-3 – This 4D model helped the CCM team to decide that it would be beneficial during construction to move a water retention wall from the south side of a building to the north side. The CCM team hoped that this decision would ease the later construction activities, as the work on the building and the work in the excavation pit would thereby be decoupled.

Figure 5-4 – This example shows how the CCM team used the 4D system to design the temporary supports for an excavation pit. The CCM team used the 4D model to make the decision that it is possible to support one side of the excavation pit with a truss instead of using tiebacks. The CCM team hoped that a support with a truss would be beneficial for the work in the excavation pit because the tiebacks' supports would require space within the pit.

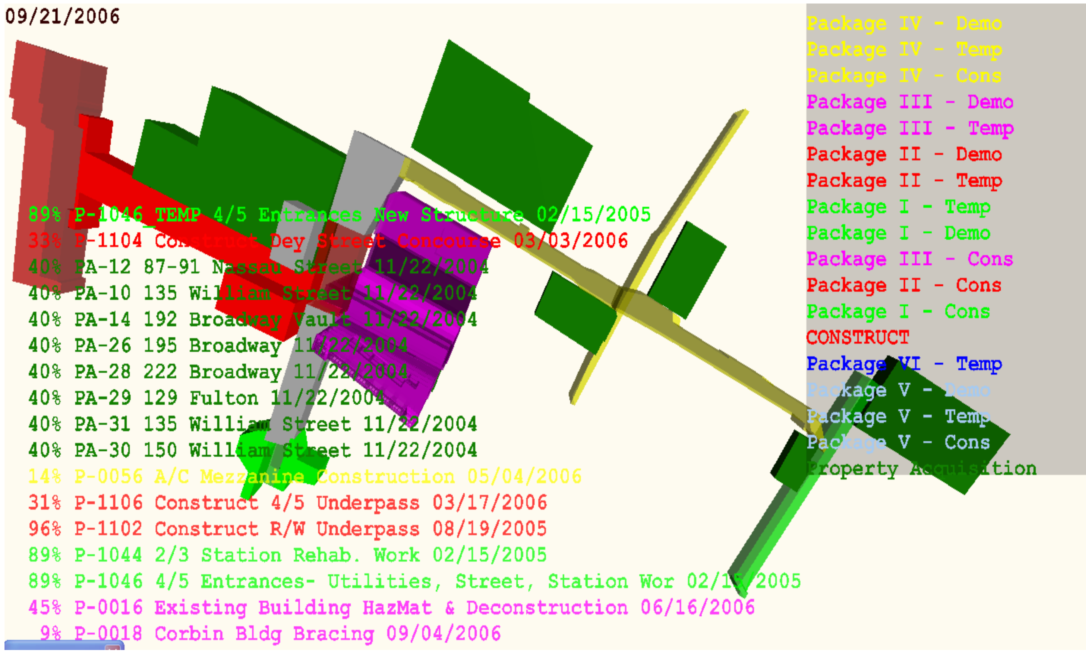

Figure 5-5 – This 4D model presents an overview of the site and was linked to the overall Master schedule. This 4D model supported the CCM team during a number of decisions with respect to high-level master scheduling and contract packaging.

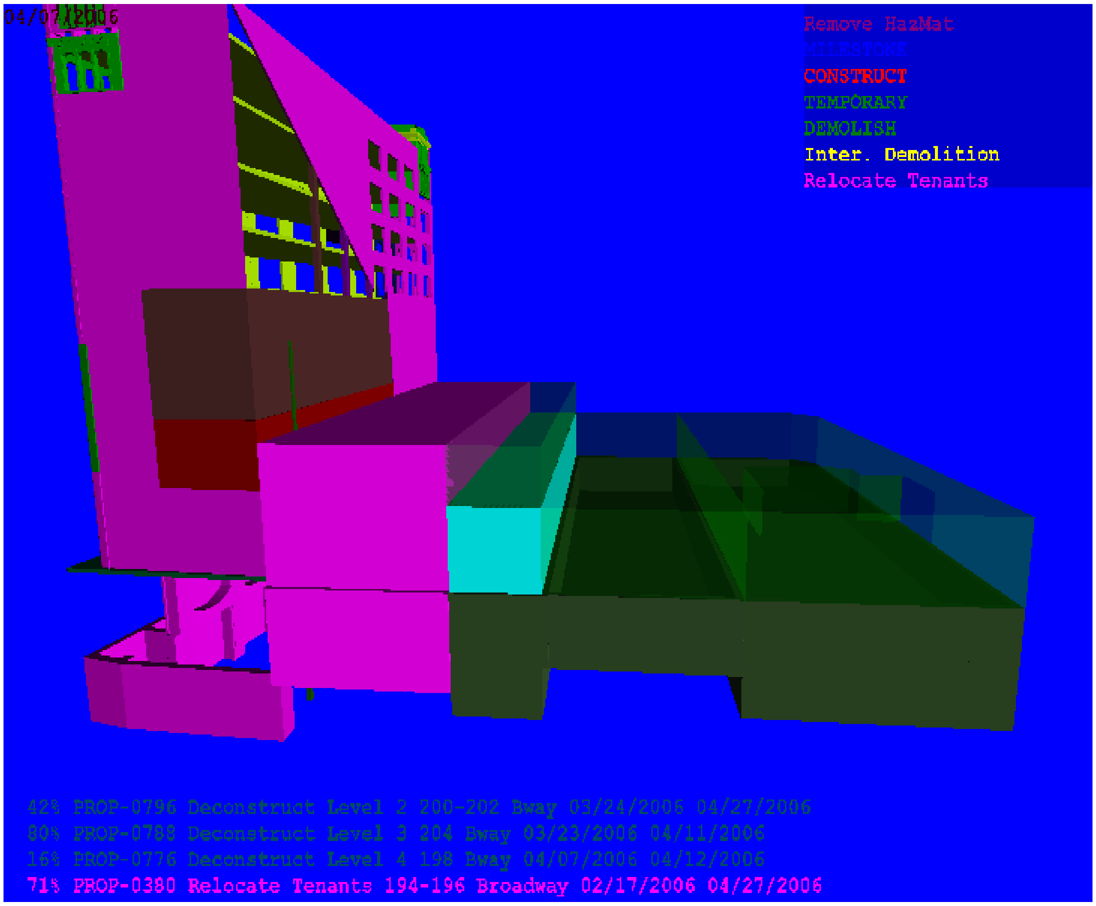

Figure 5-6 – This 4D model supported decisions of the CCM team during planning activities of how to best relocate tenants of a number of buildings that have to be demolished during the construction activities. The CCM team used the model to plan the sequence of relocation of tenants, removal of hazardous material, and demolition.

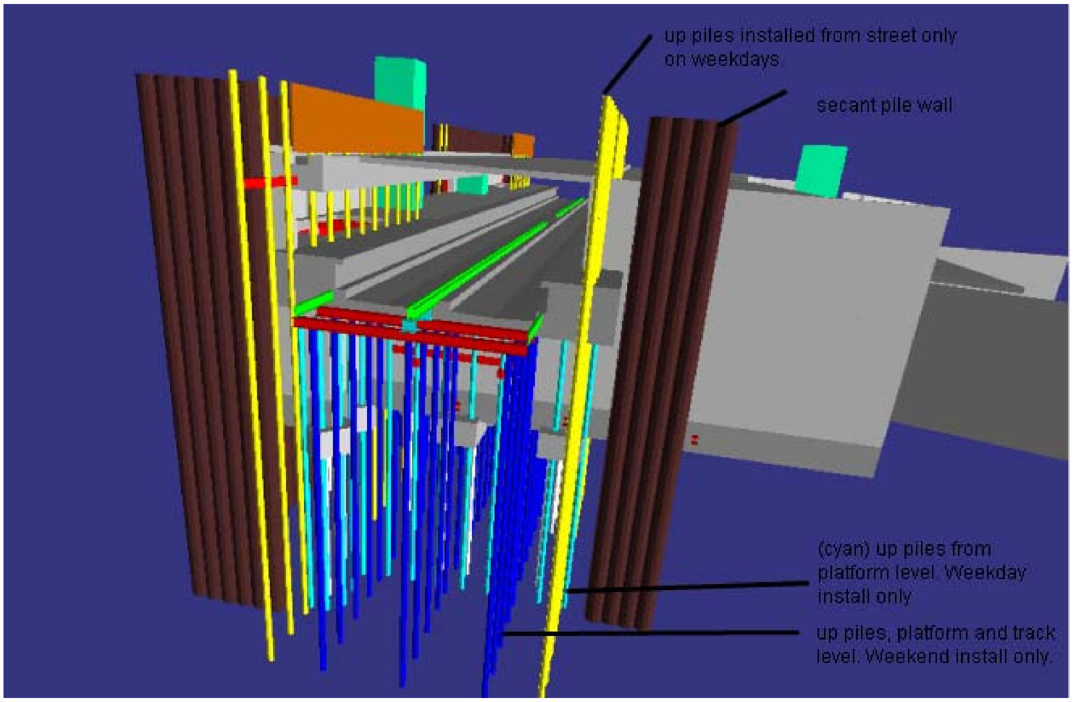

Figure 5-7 - This 4D model of piles to support one of the subway stations was helpful for the CCM to decide how to best sequence the pile driving activities. The CCM team used different colors to distinguish between different requirements for the piling activities and linked the 3D model to different alternative pile driving schedules.

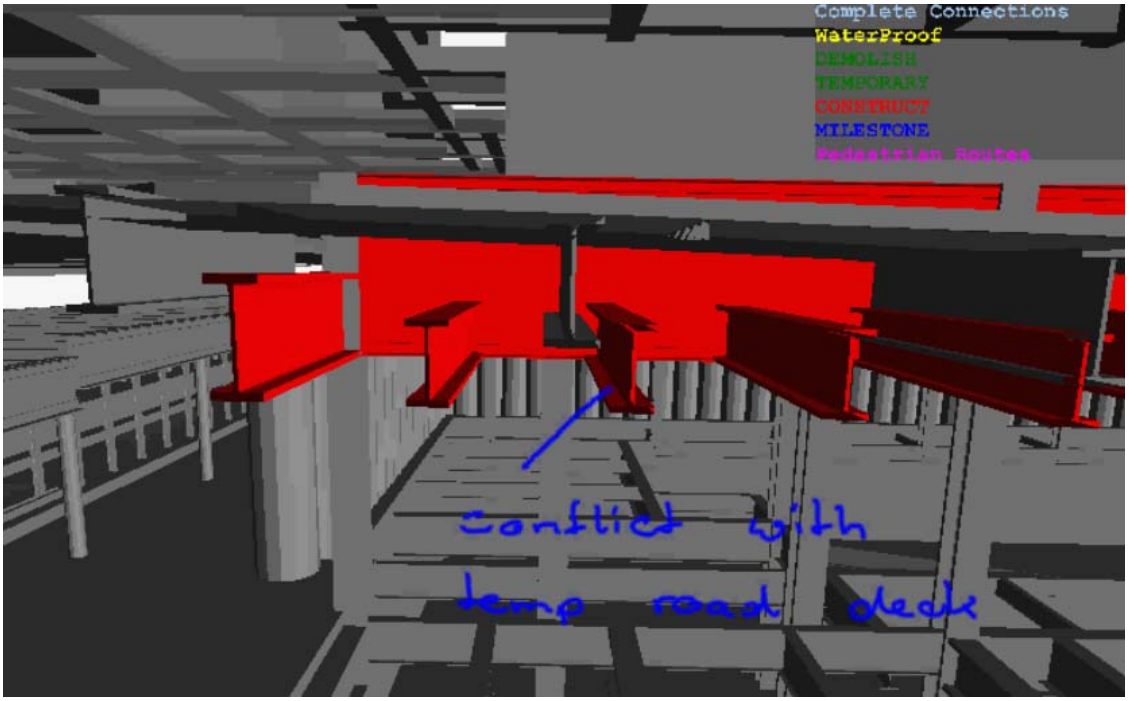

Figure 5-8 - This 4D model supported the CCM team to make decisions about the closure of a road to allow underground construction. Initially, the CCM team planned to install a temporary road deck that would allow maintaining the street traffic while carrying out construction work below. However, using this 4D model, the CCM team realized that there was not enough space to support such a temporary road deck. Therefore, the CCM team made the decision to close this street during construction.

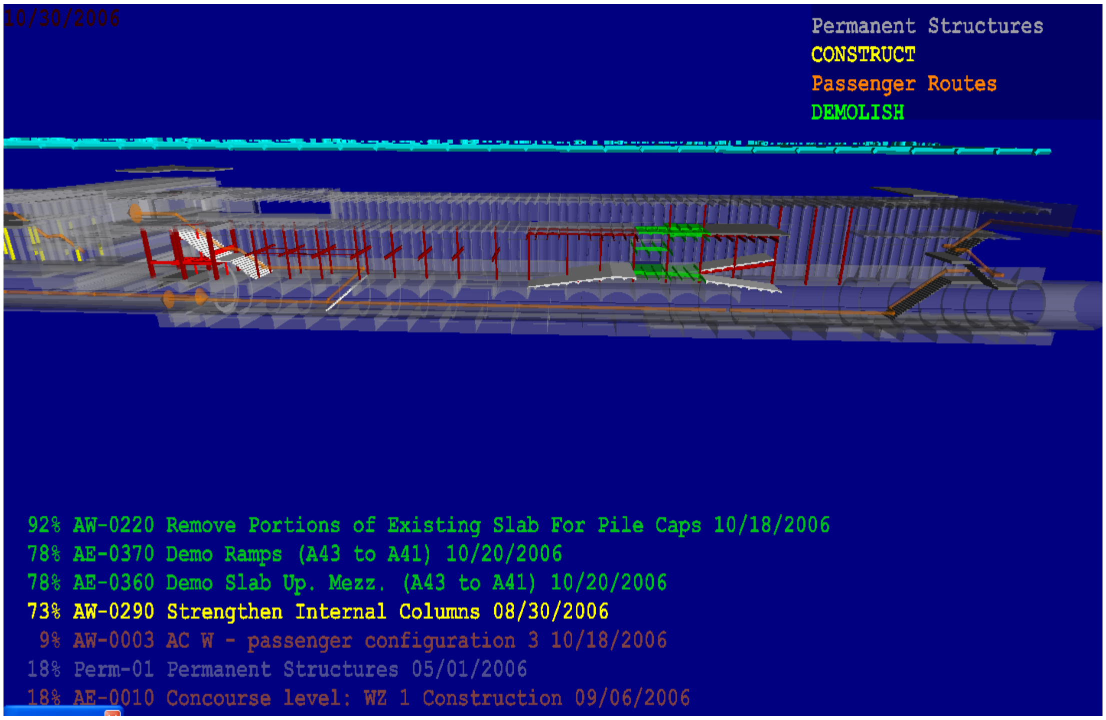

Figure 5-9 - This model supported the project team during their evaluation of whether it is possible to maintain access to the subway lines for passengers during construction. The model displays passenger routes with orange lines, construction activities in yellow, and demolishing activities in green. The CCM team used this model during a number of meetings to iteratively evaluate different passenger routes and construction sequences. In the end, the model supported the CCM team to make the decision to approve the design of this station as constructible under the constraint of maintaining the subway operations at all times.

5.7 Construction Drawings

During my fieldwork I collected all official construction documents because they helped me to understand the technical reality of the project better. Overall, in the two years of research I collected more than 4,500 drawings. Additionally, I collected around 20 marked up drawings that project team members marked during several decision making meetings to capture decisions that were made. During data analysis, these marked-up drawings served as evidence for decisions that were made without the support of the 4D system. In this way, the marked up drawings were especially useful to triangulate the observed technical reality.

Figure 5-10 shows an example of such a marked-up drawing. Project team members marked up the drawing while they were planning a sequence of installing a number of piles.

The mark-up then also served as a reference that project team members used to track the decision later. During the successful phases of the use of the 4D system, the project team replaced the use of such mark-ups with the 4D system (compare with Figure 5-7).

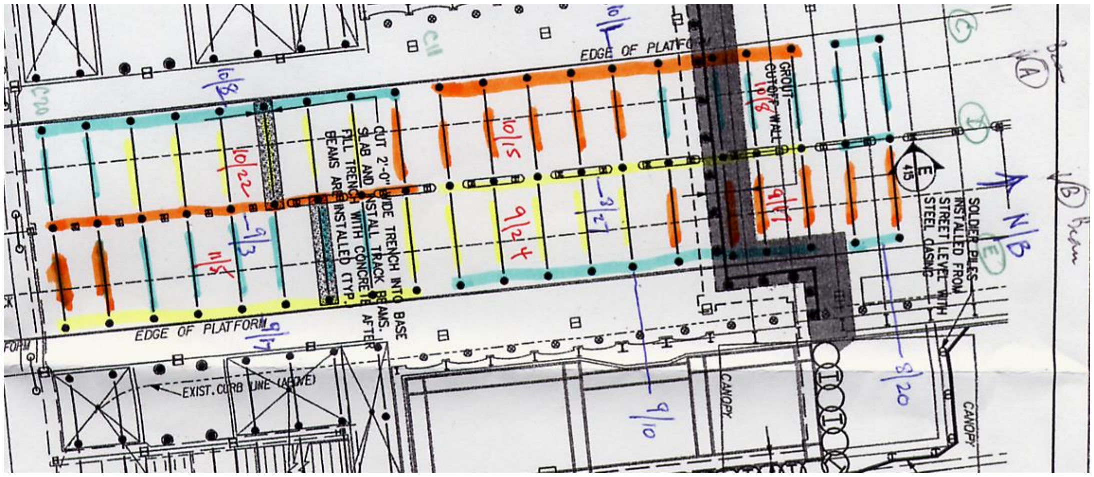

Figure 5-10 - Marked up 2D drawing of the scheduled piling sequence

5.8 Presentations

Throughout the participant observation on the project, project stakeholders, including myself, gave a number of different presentations to a wide variety of different audiences. In a number of these documentations, CCM team members and the client used 3D and 4D Models to communicate complicated issues to engineering and non-engineering audiences. While I did not include this use of the model “as a reported successful use of the 4D system to support decisions”, the presentations were still an important indicator for the prevailing spirit on the project. I attended some of these presentations and I collected the power point slide shows that were used in each of them. These are the presentations that I deemed important during my data analysis:

- 2-9-2004 Constructability review workshop presentation
- 7-7-2004 CCM team presentation to the client – state of constructability review
- 8-30-04 CCM team presentation to the client – state of constructability review
- 9-10-04 CCM team presentation to the client – state of constructability review
- 11-22-04 CCM team presentation to the client – state of constructability review
- 12-7-04 CCM team presentation to the client – state of constructability review
- 12-13-04 CCM team presentation to the client – state of constructability review
- 1-25-05 CCM team presentation to the client – state of constructability review

- 5-3-05 Presentation to company internal non-project team members about how to use the 4D system
- 6-13-05 CCM team presentation for the client – 4D benefits
- 11-11-05 Presentation of one of the project team members to a delegation of his company from Australia that wanted to learn about the 4D system

5.9 Meeting Minutes and Meeting Participation Lists

Meeting minutes turned out to be a very important source of information about two different constructs. First, meeting minutes helped me to analyze the evolving spirit of the project team members about the 4D system in a number of 4D management meetings that occurred regularly at the beginning of the effort, but also, not so regularly, at later implementation stages. Second, meeting minutes about construction management meetings helped me to analyze the technical reality. Meeting minutes also helped me to detect a number of effective uses of the 4D system to support decision making. Overall, I was able to analyze 26 different 4D-related meeting minutes throughout the two years of observation.

Below is an example of one of these meeting minutes that I also used as evidence in chapter two:

[Project]
Meeting Minutes

Date: November 02, 2004
Time: 3:30pm
Place: [Company Offices]
[Some Street]
[Some Meeting Room]

Attendees: ***Project Manager 1***
Office Engineer
Scheduler
4D Specialist 1
4D Specialist 2

Purpose: Getting an overview of the existing 4D model for the [a part of the project]

- ***The 4D environment used for the meeting was as follows:***
  - ***Software used was [Software Application] v1.95 for 3D model viewing and 4D simulation and [Electronic White Board] for screen markup and capture.***
  - ***The model file used was SiteModel-10-27-04_Linked. This model file contained 3D geometry for the [4 different parts of the project].***
  - ***The [2 parts of the project] were linked to a [scheduling software] schedule developed by [Scheduler], [Office Engineer], and [Project Manager] of [Joint Venture Company]***
  - ***4D Specialist 1 started the 4D simulation showing [an] area of the model.***
- ***The participants discussed that the construction of the secant pile wall should be represented as a continuous process. [4D Specialist 1] said that the schedule received by [the Scheduler] needed to be structured new in order to show this process continuous in 4D.***
- ***As next point the team discussed the temporal bracing for the [a] Passageway. Project Manager 1 mentioned that the vertical spaces between the bracings in the model should be one third of the overall depth of the fully excavated area. [4 Specialist 1], [4D Specialist 2] and [the Project Manager] then evaluated the possibility to reduce the levels of bracing. One alternative discussed was that one bracing level could be simultaneously used as the steel framing for the proposed passageway roof.***
- ***The team then decided to model the basements and vaults of the adjacent buildings until the next meeting. This would enable, among other things, a better evaluation whether construction alternatives are feasible due to the constraint space conditions on both sides of the planned passageway.***
- ***After consulting the 4D model and verifying it with the drawings [4D Specialist 1] and [4D Specialist 2] updated the other meeting participants about a change within the design. [The design company] plans to construct additional foundation piles with pile caps on the North-East side of the passageway at the intersection with [a street]. This change is incorporated into the Extended PE submission of August***

2004 and is shown in the model.

- ***The team discussed and evaluated the restricted space conditions at the east end of the [a] passageway on the intersection with [a subway line]. Within this area there is a mezzanine level above the passageway, restricting the area between the planned underground construction and the street. The team discussed a couple of alternatives. However it was decided that a further investigation of these points should be made in the following meetings after validating the accuracy of the model.***
- ***Due to the restricted conditions it will not be able to construct a temporal road deck. The model showed that the temporal beams of the road deck would overlap with the proposed beams of the mezzanine level. However it might be possible to entirely close down [a street] for the construction that needs to be done under the east part of the road.***
- ***It was decided to thoroughly investigate the existing and proposed utility conditions. Based on this investigation the constructability concerning the possibilities to reroute and support the utilities has then to be evaluated.***
- ***The underpinning of the [a] underpass was discussed briefly. It was realized that the model used a color code for these piles. However the team could not determine the meaning of the different colors. 4D Specialist 1 suggested that [a 3D Modeler] colored the piles according to a sequencing document [the Design Company] published. It was decided to either provide a color legend within the next meeting or to use a unique color for the piles so a distraction in following meetings could be avoided.***
- ***It was decided to discuss the following action items within upcoming meetings. Furthermore necessary changes in the model were discussed in order to show these action items adequately:***
    - ***Incorporating the right sequence in the schedule. In was decided that [the Scheduler] will present a new schedule by the beginning of the next week that is then linked into the 3D model by [4D Specialist 1] and [4D Specialist 2].***
    - ***It was decided that [a 3D Modeler] and [4D Specialist 1] will investigate the model accuracy of the east side of the [a] Passage. Furthermore [a 3D Modeler] and [4D Specialist 1] will investigate the existing and proposed utility conditions of this***

part of the site.

- ***[A 3D Modeler] will change the coloring of the underpinning piles of the [a] underpass or provide an adequate legend for his color codes.***
- ***[The Scheduler] and the [Office Engineer] will provide a GO schedule by beginning of next week that can then be linked into the model by [4D Specialist 1] and [4D Specialist 2].***
- ***[4D Spcialist 1], [4D Specialist 2], and [a 3D Modeler] will investigate the type and amount of work that needs to be carried on West of [a] Street. Furthermore [4D Spcialist 1], [4D Specialist 2], and [a 3D Modeler] will evaluate the best way to update the model to accurately simulate this work.***
- ***[The Project Manager] will invite [the Design Company's] structural engineers in order to discuss the feasibility of different construction and design alternatives in one of the following weeks.***

In addition to the meeting minutes, sign up sheets in meetings were an important source of information about who participated in the 4D effort. While, at the beginning, the CCM team only used a simple sign-in sheet for names, Email address, and phone number of the participants, later on, the CCM team started to use more advanced sheets. The team, for example, used a questionnaire to subjectively ask meeting participants, how much time they believed that they saved during the meeting with the 4D system (Figure 5-11). Furthermore, the CCM team used a sheet in its project office meeting room to capture which technology was used during each meeting (Figure 5-12).

Comparision of 4D vs. Traditional 2D + Schedule

Date:	
Start:	
End:	

Discussed Topics:

Solutions Quality Key

Better Quality	2
Slightly Better Quality	1
Same Quality	0
Slightly Worse Quality	-1
Worse Quality	-2

Position	Company	Time Saved Describing	Time Saved Evaluating	Time Saved Predicting	Number of Solution Alternatives that could be evaluated	Overall Quality of Solutions found compared with 2D (see Key above)

Notes:

Figure 5-11 - Meeting Evaluation Sheet

[redacted] Board Use

[redacted]

Date of Mtg:	11/1/2005
Time of Mtg:	8:30AM
Planned Duration:	2 Hours

Attendees

Name	Organization	Email	Phone
[redacted]			

Purpose[redacted]eting:
Evaluate [redacted] Project Logistics - Especially Contract 3 and Crane Locations for Transit Center

Actual Duration:
2 hours

Percentage of [redacted]board use: 75

Software Used:	Purpose of use:	Method of [redacted]board Use:
Various 3D visualization	Work on Project Logistics	Presentation on full screen, markup, highlighting

Mark up Files Saved As:	None
Mark up Files Transferred / Emailed to:	None

Figure 5-12 – Example Meeting Sign-Up Sheet from the Project

5.10 3D Model Change Database

After initial problems with managing the different versions of the 3D models, the CCM team established a database to store changes in 3D models. The database stored the date of each change to a 3D model, who remodeled the change, and on what input data the respective 3D modeler used to generate the 3D model. Figure 5-13 shows the graphical user interface of the database.

During data analysis the database was a great reference to track changes in the 3D models. I triangulated these changes with the recorded uses of the 4D model to understand whether changes of the 3D part influenced how project team members used the 4D system.

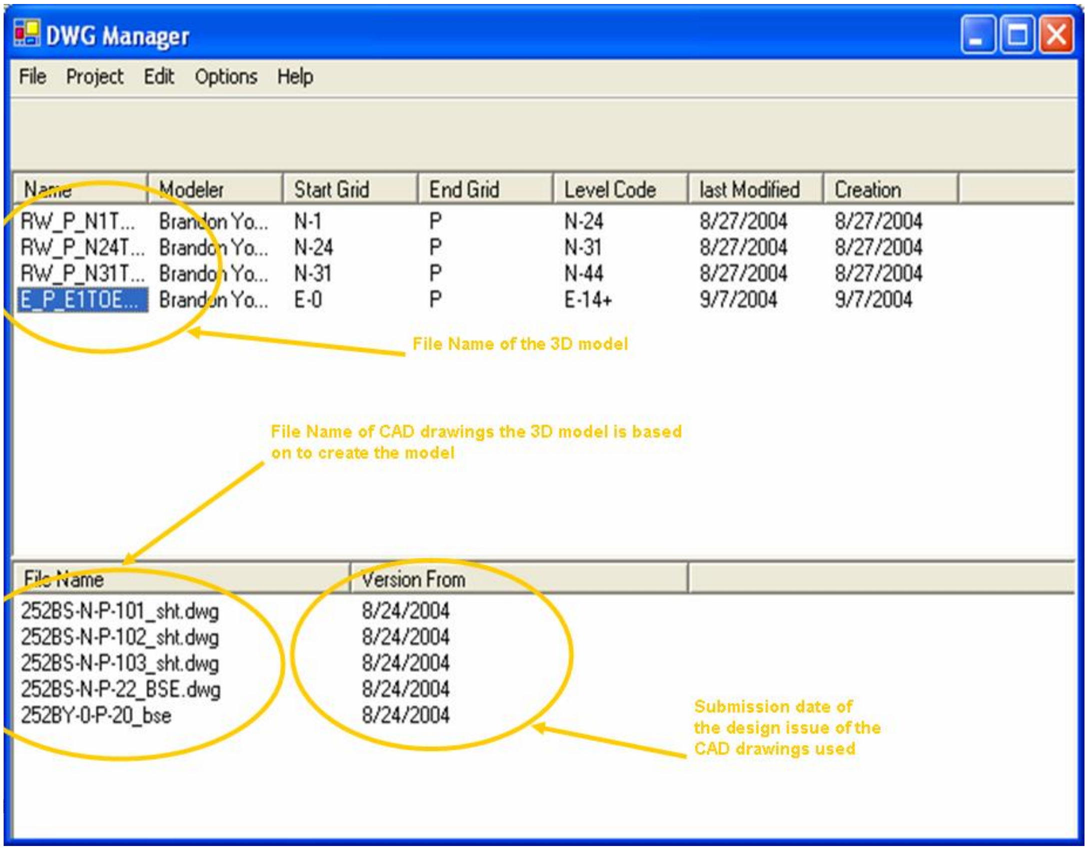

Figure 5-13 - Graphical User Interface of the 3D Model Change Database

5.11 Other Documents

Throughout my field work I collected a large number of other documents. For example, I had access to 241 different requests for information about design issues from various contractors or to 2201 formal submittals of various contents that were logged in a project database. However, because of the large number of these documents I was not able to evaluate all of these documents within the scope of my Ph.D. research. It is questionable whether a more detailed analysis of all of the documents would have significantly contributed to my results. I expect that most of these documents have no relations with the 4D system implementation efforts. Therefore, in the end, I only used a small number of specifically selected formal submittals that were logged in the database to triangulate the constructs of technical reality and utilization:

- Two funding applications for the 4D effort,
- A 3D model conversion chart,
- A 3D naming convention work break-down-structure,

- The Master schedule (evolving throughout the project),
- Different submitted versions of contractor schedules,
- The CCM team man hours Apr-04 – Feb-05, or,
- The document “Thoughts on the [projects] 4D effort” that was distributed as a memorandum among the team members
- Several revisions of the official “Project Constructability and Scheduling Review Report” published by the project’s design team
- Several CAD manuals published by the project’s design team
- Several “Contract Packaging Plans” published by the project’s design team