Examining the Process of Automation Development and Deployment

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Applied Science
in
Systems Design Engineering

Waterloo, Ontario, Canada, 2005

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

In order to develop a better understanding of the process of development and deployment of automated systems, this thesis examines aspects of project execution and knowledge transfer in the context of a large automation project.

Background issues of project execution are examined, including the challenges of knowledge sharing in project development, as well as a brief discussion of measures of project success. The lifecycle of a large automation project is presented, including aspects of development and the development team, as well as design challenges inherent in the development process of a successful automation project which consisted of approximately 11,000 hours of combined effort by vendor and customer development teams.

Human factors aspects of large automation projects are explored, including an investigation of the workings of a large project team, by examining the cognitive aspects of the project team, as well as ecological aspects of the automation development process.

Using an interview methodology that can be termed the “echo method”, project team members were interviewed in order to elicit helpful and unhelpful behaviours exhibited by other team members throughout the project. The results of these interviews are categorized and examined in the context of both knowledge management and social networks. Common themes in interview comments are identified, and related to both the areas of knowledge management and social networks.

Results indicated that team member experience and availability affect overall team performance. However, overlapping capabilities within a team were found to allow the team to adapt to changing circumstances, as well as to overcome weaknesses in team member availability. Better understanding of team interactions and capabilities supports improvements in project performance, ultimately delivering higher quality automation and streamlining the development process.

Acknowledgements

I would like to thank my supervisor Professor Catherine Burns for her support and flexibility in allowing me to explore the nature of automation development in ways that were not originally anticipated at the outset of this project. I would also like to thank Professor Robert Duimering for his guidance and suggestions.

Additionally, I would like to acknowledge the support and interest of my interview subjects, and express my thanks for their patience and feedback.

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Chapter 1
Introduction

Automation projects, like software projects, depend on a wide variety of people, circumstances, and variables to be carried out successfully. With the assembly of a large project team, having members with varying degrees of skill, expertise and experience, the coordination of effort required to complete such a project becomes critical to the overall success of the project. As such, the interaction of team members, both in behaviour and communications, require examination to better understand the activities that influence successful projects. Investigation into the factors influencing successful projects has been diverse (Brown, Klastorin et al. 1990), examining the characteristics of the team, the task, team collaboration, and several other factors. However, the automation development team, composed of both vendor and customer personnel, presents unique challenges due to the necessary interactions of vendor and customer personnel, wide range of necessary team member experience, and the pressures of production.

The objective of this work is to identify the elements that contribute to successful automation development, as well as to examine factors that lead to complications in project execution. This work then ties better project execution to the development of better automation and better systems in general.

1.1 The Implications of Investigating Automation Development

Any person involved in a non-trivial project can enhance their performance in that project, as well as the overall performance of the project team, through better understanding of what behaviours influence project success. Customers, vendors, and in-house project teams stand to gain from a better understanding of what contributes to successful project execution.

1.2 The Project

A Kitchener, Ontario based Automation Engineering vendor was contracted by a major Canadian steel manufacturer to engineer and commission programmable logic controller (PLC) upgrades that were to replace legacy hardware and add functionality to Blast Furnace charging operations without interrupting production.

An examination of the lifecycle of a large automation project is presented so as to highlight the challenges involved. More detail of the project in question can be found in (Barsalou, McMillan et al. 2004).

1.3 Motivation

Retrofit automation projects often involve mission critical applications where downtime is costly and may occur only in short periods. As such, upgrade and retrofit projects often require careful planning in order that they may be commissioned with a minimum of downtime.

Typical retrofit projects often involve complete tear-out and replacement of the control hardware, as well as re-wiring of the system, requiring a significant length of time in order to install as well as test the newly installed system. In the event that an extended stoppage is available, the automation may be installed and commissioned during the stoppage. The time required may be on the order of a weekend, several weekends, or a period of a week or more.

In a process that is regularly stopped, a project may be structured so that sections of the upgrade may be deployed during these periodic stoppages. However, there are some processes that once started, cannot be stopped for more than a few hours or days. The blast furnace, used to reduce iron ore to molten iron, is a prime example of this; typically a blast furnace will run for several years between full-scale stoppages.

In downtime intolerant systems, the need to upgrade existing equipment in a timely manner requires that projects be tested and commissioned during regular operation, taking advantage of brief maintenance stoppages in order to make any changes that may have an impact on normal operation. With potentially years passing between full stoppages, replacement of failing equipment or implementation of process improvements often cannot be deferred.

For the continued operation and safety of the process, the team assembled to complete such projects must be highly skilled, taking steps to ensure that the process is not interrupted, and that the physical safety of those involved is not compromised. This project was a major effort, comprising of approximately 11,000 person-hours of effort split between customer and vendor project teams. (Barsalou, McMillan et al. 2004).

1.3.1 Research Approach

In order to develop a greater insight into the process of automation development and deployment, a completed project was selected for analysis. The project was chosen due to both familiarity of the author with the subject matter, as well as the accessibility and cooperation of the development team. Additionally, the project as a whole was viewed to be successful, with some complications arising during development and deployment. It is expected that analysis will shed light on the areas where the project was truly a success, and areas with room for improvement.

Through the use of one-on-one interviews, the reflections of the development team were solicited. A script of interview questions was developed for use during these interviews, which included questions regarding individual and team member performance, as well as the project as a whole.

Analysis of the results of the interviews attempts to find patterns that support better project execution. The analysis also examines the characteristics of the team from a social network perspective.

1.3.2 Contributions

Examination of the mechanics of project execution will allow both project managers and project team members to better understand the effects of their behaviours on the overall outcome of large projects. Due to the inherently complex nature of both domain knowledge (specifically, the operation of a blast furnace for the purpose of making iron) and technical knowledge involved in such projects, team members must learn to better leverage the tools available to them.

Often these tools are predominantly the skills and knowledge present in other team members. While the overall success of any project is subject to various factors, providing project team members with a better understanding of the effects of their behaviour will allow them to improve upon their individual contributions to overall project performance.

This thesis combines aspects of social network analysis and interview methods to examine the process of automation development from a new perspective, in an effort to develop insights and measures that will lead to better project management and ultimately better projects.

1.4 Thesis Organization

Chapter two examines the background issues of project execution, including an outline of the areas of knowledge management and social networks. The lifecycle of a large automation project is presented, including aspects of development and the development team, as well as design challenges inherent in the design process. Chapter two ends with a discussion of project success and project savings.

Chapter three highlights the human factors aspects of large automation projects. Similar to the concept of "cognition in the wild" as presented by Hutchins (1995), the workings of a large project team exhibit emergent cognitive characteristics beyond the sum of the individual contributions.

Chapter four presents the investigation of the project, outlining the selection of project for study as well as the methods of study used. Chapter five presents the results of this investigation and attempts to summarize these results in a useful and clear manner, in both a knowledge management and social network framework.

Chapter six draws conclusions based on the results obtained, with a discussion of the results and an examination of the implications and limitations of this work. A brief outline of potential future work is also provided.

Chapter 2
Background

Inherent in the scale of a large automation project are several challenges. As presented in (Barsalou, McMillan et al. 2004), execution of such large projects involves the coordination and cooperation of a diverse team of both vendor and customer personnel. In order to better understand the role that team member skills and knowledge play in the execution of the project, an examination of the project in the context of knowledge management and social networks will be presented.

2.1 Knowledge Management

The realm of knowledge management (KM) typically examines methods of making high quality knowledge available to members of a project team, in order to "produce bottom line benefits by making better use of an organization's intellectual capital" (Gray and Meister 2004). As cited in the work of Gray and Meister, financial gains have been seen due to the sharing of knowledge within organizations. In addition to knowledge made explicitly available, behaviours which seek out knowledge when necessary enhance the overall performance of organizations.

The authors state that "the knowledge sourced from others benefits them more because it compensates for their own lack of effective experiential learning." This is especially true in large automation projects, where it would be unreasonable to expect that all team members already have or are capable of obtaining complete knowledge of the system under examination. Given the range of technical challenges that can be seen in large automation projects, as was seen in (Barsalou, McMillan et al. 2004), it can be daunting for less experienced team members to face multiple generations of hardware and software, in addition to having the need to develop knowledge of new process subject matter.

Holsapple and Jones (2004) cite empirical studies to present a picture of knowledge management that indicates that "competitive advantage" is directly influenced by "what the organization knows, how it uses what it knows, and how fast it can know something new." In their work, the authors cite several surveys that indicate that knowledge is critical to an organization's competitiveness, yet very few organizations – six percent of organizations in a particular study (Chase 1997) – rate themselves as "very effective" in their use of organizational knowledge.

Manufacturing carries significant demands for process, control, and contingency knowledge, which is often volatile and stored only in the brains of employees, since much of the knowledge takes tacit forms, developed through the years of experience (Kim, Hwang et al. 2003). As such, understanding the mechanisms of the storage and sharing of this knowledge in a project team can be useful in understanding the performance of the team. Bhatt (1998) has examined the nature of unstructured, people-centred knowledge, and has found that personal experience and social relations are important in organizational knowledge management.

A brief examination of the social network structure of the project team will be presented, in order to highlight the interaction and flow of information necessary to complete the project.

2.2 Social Network Analysis

Social network analysis is useful in the examination of relational data, that is, "the contacts, ties and connections, the group attachments and meetings, which relate one agent to another and so cannot be reduced to the properties of the individual agents themselves" (Scott 1991). Through the use of social network analysis, the links between project team members can be summarized and examined in terms of connectivity and stability.

While this thesis is not intended to be an explicit investigation of social network analysis, concepts of social network analysis are useful in highlighting the interaction of project team members.

2.3 Expectations

It is predicted that this investigation will reveal that the success of the project was influenced by effective communication between team members, including both vendor and customer teams. Effective communications can be seen as providing "the right knowledge or information to the right person at the right time and at the right level" (Dieng, Corby et al. 1999).

Additionally, it would seem that the success of the start-up was due to thorough process understanding and comprehensive integrated testing and commissioning.

However, it is also expected that the investigation will highlight areas where improvement is possible and perhaps necessary. While the project in question has been acknowledged as successful (Barsalou, McMillan et al. 2004), it is unreasonable to assume that there will be no deficiencies or areas requiring attention.

It is anticipated that the interview results will show that team members acknowledge and value the experience and broad range of knowledge of the domain experts present in the team. In light of this, identification of the behaviours contributing to thorough process understanding in other team members, as well as those leading to effective communication between team members, will hopefully aid in the future execution of similar projects.

2.4 Project Elements

In order to better understand the characteristics of a successful project, as well as the challenges involved in delivering automation, it is useful to examine the elements of the project development cycle. A typical automation project will proceed through several phases of specification, development, and testing, before proceeding to implementation.

Project phases can include (Barsalou, McMillan et al. 2004):

Functional Specification – the customer and / or the vendor develop a comprehensive specification of system functionality to be used as a design document for development.

Electrical Design – the customer and / or the vendor design necessary electrical systems for the project.

Software Development – the vendor develops software to meet the requirements of the customer, as outlined in the request for quotation and the functional specification

Simulation Development – the vendor develops simulation logic used to test the functionality of the software

Testing – the vendor tests the software developed against the simulation that has been developed. On completion of development and in-house testing, a Factory Acceptance Test (FAT) is carried out, where the customer accepts the system for installation.

Installation – the customer, vendor and / or installation contractor install necessary hardware and software at the customer site

Cold Commissioning – the customer and vendor coordinate to test all system input and output points before starting integrated system testing

Warm Commissioning – once I/O has been verified, system elements and sequences are tested to determine functional correctness

Start-up – once functional correctness is determined, the system is started up for production

Monitoring and Tuning – once production has started, problems are corrected, and system performance is tuned

Training – throughout commissioning and start-up, maintenance and operations personnel are trained in aspects of system functionality.

2.4.1 Functional Specification as a Knowledge Management Tool

In essence, the functional specification is developed as an attempt to transform tacit knowledge (that is, the unwritten knowledge held by both customer and vendor) into explicit knowledge that may then be combined with other explicit knowledge to produce a complete automation design.

However, the functional specification may not encompass all of the tacit information held by the subject matter experts and developers, and as such, the functional specification is not the only manner in which knowledge is transferred between team members. The work of (Kim, Hwang et al. 2003) examines both the flow of knowledge and its extraction in a manufacturing environment. This mirrors, to some extent, the process of developing a functional specification.

2.4.2 Development

Since much of automation development is in fact software development (in the form of control programming, communications, and Human Machine Interface – HMI – software), it is useful to examine the automation development cycle in the same manner as the software development cycle. The concept of software process maturity – specifically, the Capability Maturity Model (CMM) developed by the Software Engineering Institute (SEI) outlines a model that defines five levels of "maturity" for an organization (Parasuraman and Mouloua 1996):

Chaotic – software is developed "by the seat of their pants and the heroic performance of highly competent people."

Repeatable – chaotic development with the addition of project planning, tracking, quality assurance and configuration management.

Defined – process of development that is followed has been written down, practitioners understand the procedure, and steps are taken to make sure these procedures are followed.

Managed – metrics are added to the defined level, so as to better understand and control the development process.

Optimizing – added to the managed level is continuous improvement based on quantitative data.

It is often the case that custom automation development operates in the first three levels of this model. It may be that the chaotic level is the highest level reached; the key to success in this level is indicated to be "heroic performance of highly competent people". It is interesting to note that the converse of heroic performance by highly competent people is marginal (or substandard) performance by marginally competent (or incompetent) people, virtually assuring project problems such as delays and errors, if not outright failure. It would thus seem that achievement of only the "chaotic" level of maturity does not provide the necessary basis for repeatable project success.This examination of the automation development process is intended to move the process further along the path to development maturity.

2.4.3 Development Team

The development team can be summarized by key groupings from both the customer and the vendor. The existence of a customer development team serves multiple purposes. Firstly, the customer must have some mechanism of establishing or accepting system specifications and functionality. Additionally, in complex projects, the customer is also a source of both process and technical knowledge, and may have to complete work in conjunction with the efforts of the vendor development team in order to prepare for system installation and start-up. Team members include project lead, technical lead, technical team, electrical designers, installation electricians, maintenance, engineering, and production personnel. With several stakeholders in the development process, and with production satisfaction being the ultimate goal, communication between stakeholders is essential.

In the project examined in this thesis, the major components of the vendor development team consisted of a project lead, two PLC developers, an HMI developer, a simulation developer, a technical resource, and a tester.

The major members of the customer development team consisted of a project lead, a technical lead, two operator representatives, a maintenance lead, two maintenance electricians, an electrical designer, and an information technologies (sometimes referred to as "level two") representative.

It should be noted that while some members of both teams may have worked with each other on previous projects, the teams were assembled specifically to undertake the project under consideration, and had not worked together in this form before. (Note that the customer has contracted the vendor on other occasions, and that within both the vendor and customer, team members are chosen for each project according to availability and skills.). This adds some degree of complexity, as outlined in (Jarvenpaa and Leidner 1999), where the benefits of flexibility and complimentary competency are contrasted to the concerns of consistency, individual commitment and reliability.

Jarvenpaa and Leidner also examine in more detail the concept of virtual teams; that is, teams divided by geography that are quickly formed to suit current market needs. This closely mirrors the contracting of large automation projects to vendors – a team is formed comprised of both customer and vendor personnel, and customer and vendor personnel are often separated by geographic constraints.

While the background presented by Jarvenpaa and Leidner discusses the need for face-to-face interaction to build trust in "virtual" teams, the research presented examines the interactions of purely virtual teams (i.e. no face-to-face interaction at all). The team projects undertaken were a part of course assignments for credit. It was found that trust was developed through factors including social communication, enthusiasm, mitigation of uncertainty, initiative, predictable and timely communication, leadership, and even temperament. It would seem that such factors should also be evident in situations where teams are not purely virtual.

2.4.4 Development Challenges

The complexity of large automation projects presents many design challenges. While not all types of challenges are present in every project, variations on these challenges are often present, and must be considered.

Expert Knowledge – The nature of large projects often requires expert subject matter and technical knowledge. Not all team members possess the knowledge required, and as such must interact with other team members and resources to acquire the necessary information.

Fault Tolerant Design – In most projects, emphasis is placed on the fact that system operation must not unexpectedly stop, and that abnormal states must always have exit conditions. In many continuous processes, unexpected interruptions can quickly lead to hazardous situations, such as in cases where raw materials may continue to be consumed or temperatures may begin to rise. In light of this, the automation must also incorporate the ability to reset or restore the process to normal operation if necessary, in addition to designing so as to avoid cases where the process may become "stuck".

To some extent, anomalous operation can be tolerated very briefly, as long as the recovery from the unforeseen situation can be accomplished quickly and with minimal impact on the overall operation of the system. The implication is that in the worst case, it is necessary that a system lock-up can be averted or escaped from by some means. If nothing catastrophic occurs, quantification of the cost of such a system locking up is related directly to the time required to resume normal operation. In a twenty-four hours per day, uninterrupted production environment, every minute of delay translates to an opportunity cost. Even with a rapid response from maintenance personnel, operational anomalies can lead to non-trivial delays, as a percentage of daily production.

System design is influenced by the possible states that the process can occupy; in the event that a current state is invalid or has no exit condition (as far as the programmed automation is concerned), operator intervention will be necessary. An additional concern arises when valid operational states are encountered from which the process cannot be restarted. In this case, the operator or maintenance personnel must take manual action to place the process or machine in a valid start-up state. As an example, consider the case of the motion of a device from one known position to another known position, through an intermediate state where it is only known that the device is in transit. If for some reason, the system is halted while the device is in transit, but the motion does not complete, the system does not “know” the state of the device. Typically, for operation to be re-started, the device will likely have to be manually cycled to a known position.

Heterogeneous Systems – In a large automation installation, there is likely to be a wide variety of hardware from various manufacturers, as well as multiple means of communicating with these devices. In developing a replacement system, it is necessary to design the new system so that it can communicate with the existing devices. Additional thought may have to be given to the manner in which the replacement and operational controllers communicate, so that the timing of this communication can be determined and appropriate steps taken in order to assure adequate system performance.

As outlined in Barsalou, McMillan et al. (2004), the control systems encountered in the scope of this project spanned the technologies of multiple manufacturers and multiple generations of hardware. As such, additional coordination was necessary when dealing with communications or modifications to existing systems. This is an area where expert technical knowledge is an asset.

Simulation and Testing – Development of simulation tools for the off-site testing of an automation solution involves much of the same work that is involved in developing the actual automation programming. A deep understanding of the system is required. However, the simulation will not directly impact the process itself, and as such it may be given very little focus or credibility when compared to the automation itself.

Commissioning – The process of deploying automation can be fit within several key steps, which may vary depending on the nature of the project – new installations take a very different form than retrofit projects, and commissioning without a stoppage is significantly more different than with a stoppage.

Minimal Downtime Start-up – Process downtime is often costly; as such, every effort was made to avoid causing unscheduled downtime, and where possible attempts were made to use maintenance stoppages to best advantage, as outlined in Barsalou, McMillan et al. (2004). A key part of the ability to take advantage of unexpected downtime is the experience and wide-ranging knowledge of the project team. The transition from shadow testing to field device and communications testing would not have been possible without experienced technical personnel, especially in cases of malfunctioning field devices.

An extremely quick changeover was desired for the transition from testing to live production for the new control systems. To accomplish this, a method of shadow or parallel commissioning was undertaken. In the shadow arrangement, the new control system was run in parallel with the old, so that it could react to real process data with outputs disconnected, so as to not affect the running process.

In order to be able to carry out parallel commissioning, parallel wiring had to be developed and installed while the system is running or during brief periods of downtime. Careful planning facilitated a smooth changeover from the old system to the new system.

Overhead – In the process of developing useful simulations, as well as developing systems for shadow or parallel commissioning, there is necessarily additional expense involved in configuring the infrastructure and synchronization of the running and shadow systems. Care must be taken that elements included for the sake of simulation and synchronization are correctly removed from the production system so as not to have a negative impact in the commissioning process.

The overhead in both simulation and synchronization typically lay in the areas related to communications and speed – whether it is the speed of the simulation, or the communications between the simulator and the project. This same manner of difficulty is seen in the shadow system; where there are instances that the communications between the shadow system and the live system are not fast enough to synchronize, it becomes necessary to implement smoothing routines, or even to move small simulated segments into the shadow system. A specific example occurs with position control – the active controller is typically receiving position information every 50 milliseconds, whereas the shadow controller is seeing this information at the period of the information update cycle – which may be on the order of 500 milliseconds or more. In order for the shadow controller to "see" events that may occur during the relatively long time that it does not get updated, the internal value needs to be updated several times between communications cycles.

2.5 Project Success

Technical elements of the project and the overall success of the project have been outlined in Barsalou, McMillan et al. (2004). Specific areas of success include reduced risk of downtime arising from upgraded control hardware, cost savings due to flexible material charging, and the implementation of a foundation for further upgrades. Additionally, the project was completed with minimal impact on production.

Team members' opinions of the success of the project were also solicited, and are presented later in this paper.

2.5.1 Start-up Savings

The savings realized from a fully tested and shadowed system can be quantified by examining the cost of production stoppage at a given facility. In addition to a significantly shorter stoppage for system installation, a shadow-tested system allows for a smoother start-up in normal operation, as incorrect assumptions about system function are quickly recognized.

However, shadow testing is not a replacement for on-the-bench simulation. In the process of shadow commissioning a project, there are several elements that will likely not be tested, due to the fact that the process may not be interrupted. These include abnormal and emergency situations, enhancements in system functionality, severely timing-dependent operations, and other situations where the state of the shadow controller may diverge from that of the existing controller.

Chapter 3

Human Factors Aspects

For a large automation project, the developer must interact with computer hardware, electrical hardware, the process in question, and the people who run and maintain the process. The points of interaction between each of these actors pose several human factors challenges, including human-computer interaction, developer-operator interaction, and the sometimes overlooked developer-process interaction.

The work of Burns and Hajdukiewicz (2004) presents a brief examination of the application of ecological methods to social systems. Notable among the information presented is the discussion of the challenges involved in designing for social systems; that is, systems where “the user is not just a controller in the system, the user participates in the system.” From this perspective, the team members of the automation project can be examined from a social system perspective, in addition to the human-machine interaction perspective.

While the study of automation development from a project management perspective is not explicitly a Human Factors problem, there are elements of automation projects that tie strongly to that field, including the fact that automation projects typically deliver some manner of operator interface. Additionally, the expertise of the automation designer and process experts influence much of the manner in which operators interact with the process.

The broader aspects of Cognitive Work Analysis (CWA) highlight areas of the examination of social systems that may be insightful in the better understanding of team performance. When looking at the aspects of CWA summarized in Burns and Hajdukiewicz, several facets of the overall team performance come to light.

Work Domain Analysis presents a representation of the system being controlled, often using an abstraction hierarchy to decompose the system under consideration into higher level goals and lower level elements in a means-end relationship. For a large team, consisting of diverse interests (vendor and customer, in addition to engineering and production) the elements of the abstraction often overlap, but do not completely coincide.

In terms of control tasks (“what needs to be done”) and strategies (“how it can be done” – including examining information flow) a large project inherently divides into subtasks and the ways in which these subtasks can be completed.

Examination of the social organization and cooperation of the project team encompasses the division of labour, the management and the team structure involved in the project. Again, information flow becomes apparent in the communication involved.

The analysis of “Competencies” highlights the “knowledge, rules, and skills” necessary for fulfillment of job roles. The examination of Knowledge Management is in a sense a method of spreading elements of competency across team members and organizations. The work of Hutchins (1995) further develops the competencies of a team as being greater than the sum of individual team member competencies, in what he terms “cultural cognition”, which he studies “in the wild” – that is, in real world situations (specifically, navigation), rather than laboratory experiments. In the situations Hutchins presents, a degree of computational redundancy is seen in team performance, where the strength of the team is not only the competence of its members, but also the ability of its members to adapt to and compensate for the varying abilities, degrees of competence, and specific performances of other team members.

3.1 Social Computation

Hutchins’ also examines “social organization as computational architecture” in traditional computational terms – areas such as parallelism, communication, memory, and interfaces. Within the framework Hutchins presents, the distribution of goals and subtasks among team members may present challenges. Specifically stated is the circumstance where higher level goals are ignored after satisfaction of sub-goals, halting productivity.

3.1.1 Parallelism

Most large projects or tasks allow certain sub-elements or sub-tasks to be completed in parallel. Inherent in this capability is management of the overhead of parallelism; that is, the division and assignment of tasks, communication between parallel processes, and resynchronization where necessary.

In many ways, project management is management of the overhead of using parallelism in project completion. In project management, as in computing, it is necessary to divide the problem into tractable sub-tasks, assign resources for completion of these tasks, schedule the execution of tasks, develop protocols for communication of information between tasks, check for errors, and assemble the results. In Hutchins’ work, the ability of skilled human team members to detect and correct for errors or shortcomings in the work of others is highlighted as a key factor in making a social computational network greater than the sum of its parts.

3.1.2 Communication and Memory

From both a computational and a knowledge management perspective, communication is necessary to transfer the results of parallel processes to actors who can integrate the results obtained into a complete solution. In the navigational task explored by Hutchins, a specific protocol exists for team communication in the process termed the “fix cycle”, which is used to calculate the location of a sea going vessel as it travels. However, unlike computational protocols, violation of the standards of this protocol do not result in failure.

In less structured environments, protocols for dissemination of information may not exist – and as such, communication is often ad-hoc and unstructured. The domain of Knowledge Management can be seen as a method of developing informal protocols for information transfer and storage within organizations and teams.

In conjunction with communication, information storage and retrieval (i.e. memory) facilitate the completion of tasks by project team members. The memory of a team can be viewed at different levels. As seen in Hutchins, the working memory of team members can be used as a sort of external storage and error correction in the workings of a team. Additionally, the distilled experience of other team members serves as a resource for junior or less experienced team members, as was the case presented in Hutchins where a junior team member could not find a particular landmark, but a senior officer was able to remember from experience the general direction that should be searched.

3.1.3 Interfaces

In many circumstances, interfaces between system elements take the form of communications technologies, whether in audible or visual form, be they electronic, spoken, paper, or display. Human factors often examines the interfaces between the process operator and process itself; management science often examines the interface between team members. In terms of interfaces, automation developers can be viewed to be in a unique position.

It is possible to consider automation to be the interface between the developer and the other elements of the automation project. Through the automation, the developer communicates with the operator, in the form of human machine interfaces (HMIs) including both software based and hard-wired interfaces. Additionally, the developer communicates with the actual process – not in the sense that the developer personally runs the process (although the developer may do so in some cases), but that the automation acts as an agent of the developer, acting with the process operator to carry out the instructions of the developer in order to attain the ultimate purpose of the process.

Since the developer controls the automation design and ultimately the process, the functional goals and purposes of the process are (or should be) embedded in the design, so as to achieve the desired process results. In this aspect, the process knowledge held by the developer (both in the form of specifications and experience) is brought to bear on the control of the process, in order to overcome design challenges and anticipate failure modes. While the design and implementation can be approached purely from an intellectually mechanical perspective (i.e. focusing only on the “how”), design informed by the higher level goals (the “why”) can serve to highlight areas of weakness or vulnerability in the system. This “how” and “why” relationship closely mirrors the means-end relationship seen in the ecological interface design concept of the Abstraction Hierarchy, as can be seen in the work of Burns and Hajdukiewicz (2004).

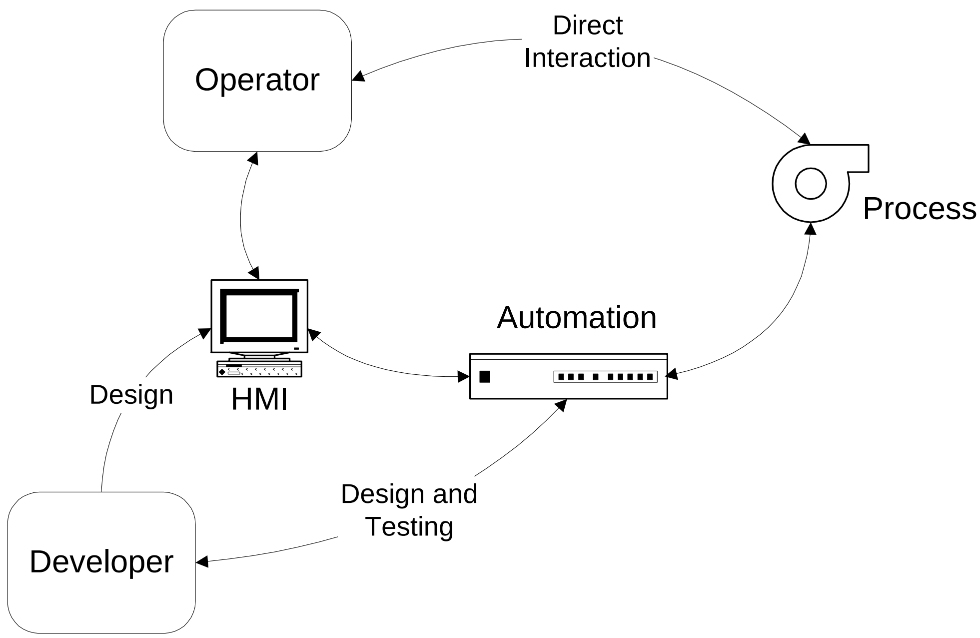


Figure 1 – Automation Interactions

Figure 1 depicts the interactions between process, automation, developer, and operator. It is necessary to note that the interactions shown are by no means exhaustive; interaction between the developer and operators is often essential to the development of such systems. However, this schematic representation is intended to highlight specific interactions between components that illustrate the knowledge and communications involved.

The operator, through experience and training, is equipped to manipulate the process both directly and through the use of a variety of Human Machine Interfaces. However, as shown in the diagram, operator interaction with the automation and automatic control of the process is mediated by the HMI provided.

The developer, on the other hand, interacts directly with the automation, in the form of designs, testing and experimentation. As such, the developer is both closer to the process (by virtue of the link from the automation) and further from the process (due to the possible lack of direct interaction). Additionally, the HMI as designed by the developer reflects the developer's understanding of the process in terms of the capabilities of the automation.

When the link between the operator and the automation breaks down, the result is that the link between the operator and the process may also breaks down. In this regard, failures in the connections between the levels result in accidents and errors, as seen in the often cited case of the Three Mile Island incident, where the state of the system as presented to the operator by the instrumentation did not reflect the actual state of the reactor, thus breaking one of the operator's links to the process (Larsson 2000), (Vicente 2003). The developer interacts with the automation more directly than the operator. However, the link between the developer to the automation is different than that of the operator and the automation; the developer can be both hindered and aided by the fact that he/she is the author of the automation – it is likely that the developer is aware of idiosyncrasies in the way that the automation behaves, including its limitations and capabilities. In the chilling example presented in *Set Phasers on Stun* (Casey 1993), an unanticipated sequence of commands used in the operation of a medical device for radiation delivery caused the device to deliver lethal doses of radiation to a patient, unbeknownst to the operator of the machine. While it is clear that the lethal mode of the machine was unintended, the case presented highlights the fact that the system developer's understanding of the capabilities of the machine must be both brought to bear in ensuring safe operation, as well as conveying to the operator a concise picture of the state of the automation.

The developer determines the cause-and-effect functionality of the automation, constrained by the physical details of the process. If the developer ignores the physical details of the process, the link between the automation and the process will break down. In this case, the operator's link to the process is also damaged, since the chain has been broken in an area beyond the area of control of the operator.

The communication between developer and operator may be both direct and indirect, by way of various operator interfaces, procedures and manuals, operator training, and feedback. Once the system has been fully commissioned, the link is only indirect – the developer's communication to the operator is fixed in the products delivered – and any shortcomings remain for the life of the system, or until an upgrade or repair addresses the issue.

In the development cycle, it is necessary to seek input from all stakeholders – including engineering design, management, and operators. Failure of this initial communications can lead to the failure of the links between the automation developer and the operator.

Communications between the developer and the process depend on the developer's understanding of the process itself. Although it would be expected that the developer fully understood the process being controlled, it may be the case that the process is incompletely specified and outside of previous experience. However, in as simple a statement as "If A is on then turn on B" is implied several consequences. These may be:

- A is an important input
- The developer knows what A is/does
- B is an important output
- The developer knows what B is/does
- It is safe to turn on B
- No other conditions prevent turning on B

It is conceivable that these implications are not necessarily true – in fact, it may be possible that few or none of them are true, but if this is in fact the case, then it may be necessary to re-examine the scope and purpose of the project under development. A conscientious developer will usually examine each of these implications – but may not actually know the function of A and/or B when writing the software. In the volume of work that is produced, it is difficult to grasp and understand all individual inputs, outputs, and the reason for relationships between them. It may in fact be a specification that states, “If A is on then turn on B” which the developer will follow carefully, and hope to understand more fully when the testing and commissioning phases of the project occur.

When the developer’s link to the process is mediated by a functional specification, rather than subject matter knowledge, the quality of the automation often relies significantly on the quality of the specification.

Further complications arise in larger automation projects – teams working in parallel on large projects may have communication difficulties and limited overlap in knowledge and expertise. Because of the complications of this interaction, additional overhead is incurred in project management and coordination, and additional complexities arise in commissioning and support. With the variety and vintages of software and technologies involved in a large scale project, support and troubleshooting often call for very adaptive and multitalented team members – able to work with both the latest software and hardware, as well as legacy applications, and understanding the interactions with other systems outside the scope of the project that may still be affecting the success of the project.

Direct communication between operators, maintenance personnel, and developers is necessary during the start-up and support stages, in order to leverage the knowledge and experience of all involved personnel. However, input from operators (and sometimes even maintenance personnel) must be tempered by the developer’s own understanding of the system – often times, operators have formed their own mental models of the process and the automation, and may make causal inferences based on coincidental events.

3.2 Ecological Aspects

While research has looked at design with the intention of involving ergonomics earlier in the process (Burns and Vicente 2000), little information can be found regarding the ergonomics of the automation design process itself. Although information exists regarding automation and its ergonomic impact (Parasuraman and Mouloua 1996), (Samad and Weyrauch 2000) as well as the process of developing control software (Bonfatti, Gadda et al. 1997), attention to the ergonomics of the process of deploying automation has been minimal.

The impact of the automation design process upon manufacturing is significant; manufacturers often add automation in an effort to increase production, reduce downtime, and improve quality and safety. Additionally, legacy hardware and hard-wired control systems are often upgraded to programmable systems that allow for significant advances in flexibility and capabilities.

As in many work domains, the process of developing automation is evolving as the technology evolves. The transition from hard-wired relay logic to programmable control has allowed automation to grow to significantly larger scales – where once there would have existed a single automated production cell there now exist several cells networked into coherent production systems (Johnson 1987). The automation designer frequently works from incomplete information, necessitating assumptions in system function and requirements (Auinger, Vorderwinkler et al. 1999). The inter-communication inherent in the design process, and the inter-communication between the multidisciplinary team required to develop these systems, both stand to benefit from the examination of the process by which such systems are deployed.

The principles of Ecological Interface Design outlined by Burns and Hajdukiewicz (2004) and system decomposition using an Abstraction Hierarchy may apply as knowledge aids in the automation design process. Of specific note is the ability of hierarchical decomposition to identify areas of poor instrumentation or sensor availability. While it may not be feasible to add “missing” sensors, illumination of gaps in the availability of measurable process data early in the design process may allow for the addition of necessary sensors, or adjustments in design mitigating the effects of such gaps.

3.2.1 The Abstraction Hierarchy

Works attempting to capture the complexity of operator tasks in a variety of domains including control room design (Burns and Vicente 2000), as well as geographic information systems in the work of Rasmussen in (Nyerges and North Atlantic Treaty Organization. Scientific Affairs Division. 1995) have used a method of describing the elements of the work domain called the abstraction hierarchy. Within the hierarchy are typically five levels with a means-end relationship; Functional Purpose, Abstract Function, Generalized Function, Physical Function and Physical Form (Burns and Hajdukiewicz 2004).

For the purpose of this examination of the process of developing and deploying automation, details of the importance at the lowest levels of decomposition will be examined briefly. It should be noted that the application of the abstraction hierarchy to a development process is somewhat challenging, as was seen in Burns and Vicente (2000). The focus on the physical levels of the abstraction hierarchy is intended to provide detail as to the volume of domain knowledge necessary for the execution of large automation projects. The abstraction hierarchy developed for the process of developing automation identified three overlapping sub-models that could be examined. Due to differing goals and responsibilities, vendor engineering, customer engineering, and customer production concerns were analysed separately.

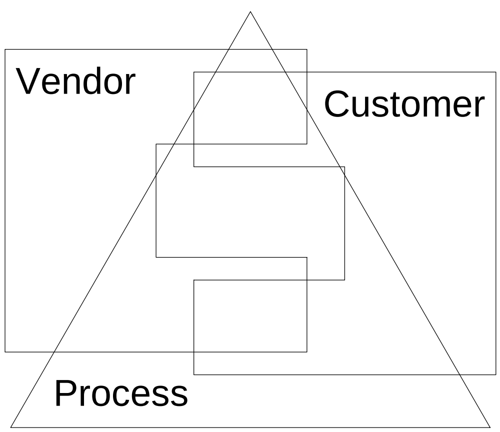


Figure 2 - Overlapping Abstractions

Figure 2 presents a schematic representation of the overlapping goals and responsibilities of the stakeholders in a large project. Conveyed in this diagram is the sense that each stakeholder has overlapping goals and purposes, but to some degree these vary, as is the case with project success – the measures of project success will vary between the vendor, where timely, correct and profitable delivery define success, and the customer project team, which may additionally have a competing goal, that being minimizing the cost of the vendor (and hence reducing the vendor's profitability). In terms of the process, the production department is ultimately responsible for running, often without interruption, and so interruptions incurred in the process of delivering a large project are contrary to high level production goals. Additionally, at the lowest level of the abstraction, the process contains the majority of the physical form elements of the puzzle.

3.2.2 Physical Function and Physical Form in Depth

While somewhat outdated, the examination of programmable controllers and hardware presented in Johnson (1987) is a strong starting point for an examination of the Physical Function and Physical Form levels of automation in the Abstraction Hierarchy. It is also interesting to note that much of the hardware presented is obsolete at this point in time, yet remains in use in many facilities.

The programmable controller for automation purposes can be divided into three broad categories; processor, input, and output (I/O). Within each of these categories are various specialized instances – numerical controllers, remote I/O scanners, network modules, and so on. Each can be considered to be a type of processor or I/O, or in some cases, both.

Individual components of programmable control systems are necessarily connected in order to develop a coherent control system. Understanding the methods of interconnection is critical in ensuring acceptable performance and avoiding downtime. An element as simple as a two-wire communications network can cause significant downtime expense.

The numerous physical function and physical form elements of an automation project would be difficult to depict in the relatively limited space of an abstraction hierarchy chart. As such, it is useful to examine a selection of them individually.

Documentation – specifications, quotations, electrical drawings, operator manuals, technical manuals

Electrical design – equipment sizing, adherence to electrical code, safety interlocking

Electrical equipment – actuators, contactors, motor starters, motor drives, relays, programmable logic controllers (PLCs), fuses, breakers, terminal blocks, I/O racks, wiring, solenoids, switches, lights, buttons, horns, sirens, analog inputs, digital inputs, analog outputs, digital outputs, encoders, bar code readers, sensors (thermocouple, semiconductor, pressure, strain, piezoelectric, capacitive, inductive, microwave, laser, mechanical, photoelectric, ultrasonic (Soloman 1994))

Control programming – code (ladder diagram, structured text, function block diagram, sequential function chart, instruction list (Bonfatti, Gadda et al. 1995)), communications configuration, functional interlocking, alarm detection

Operator interface – code (screens, scripts, loggers), alarm presentation, computer hardware, hard-wired elements (buttons, lights, switches)

Communications equipment – modems, network cards, remote I/O cabling, network cabling, industrial I/O cards, bridges, repeaters, fiber optic links

Process – valves, pumps, motors, conveyors, transfer stations, indexers, presses, hydraulics, pneumatics, load cells, storage bins, hoists

3.2.3 Programmable Controllers

At the Physical Function level, programmable controllers may be considered both electrical equipment and the housing for the control program. The function of the programmable controller is well illustrated in Figure 3, where the logical links between input, processing, and output are shown.

When considering the inner workings of a programmable controller, one of the critical aspects is the type of input and output scanning that takes place. The options are synchronous and asynchronous – that is, inputs and outputs could be processed synchronously to the program scan (after each complete scan of the logic) or asynchronously to the program scan. Complications may arise with asynchronous I/O scanning, where logic is intended to operate on a consistent input state for the duration of that scan, but in fact may be changed mid-scan. The control programmer aware of this situation takes steps to synchronize the use of I/O within the program.

When considering the physical form of an automation solution, it is useful to note that "… many of the difficulties experienced with using programmable control systems came from the external wiring to the sensors, actuators, and power applied to the I/O modules." (Johnson 1987) In light of this statement, it would be unwise to neglect the actual physical form of the automation solution; in fact, several elements of the automation solution specifically address the physical form. These include elements such as installation drawings, site plans, wiring diagrams and user manuals.

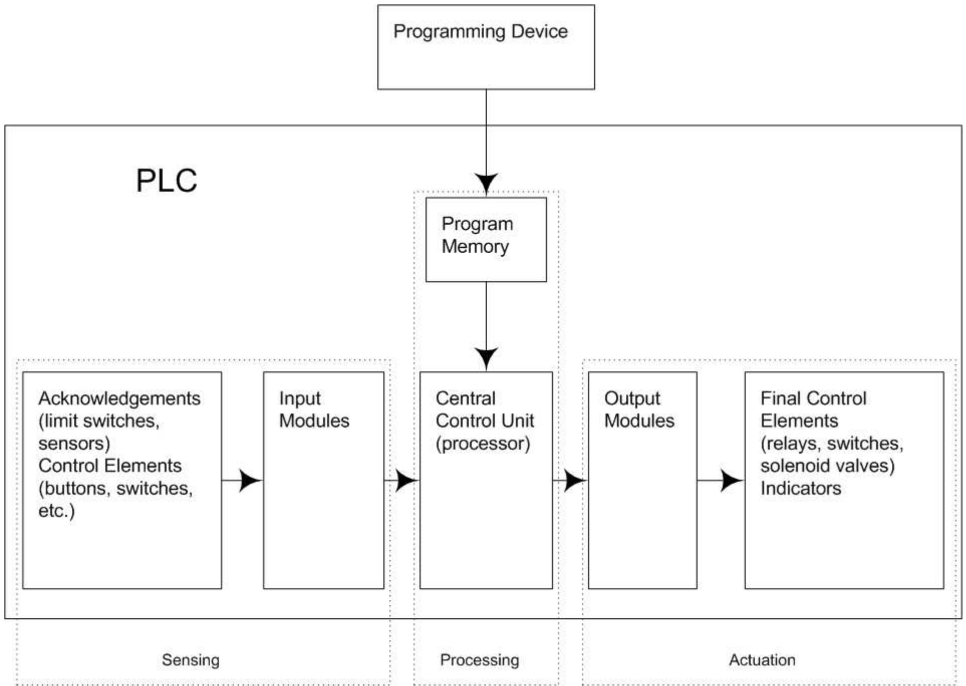


Figure 3 - Programmable Control (adapted from (Soloman 1994))

3.2.4 Important Physical Form Considerations

While there are a multitude of physical considerations to take into account in a large automation project, certain key aspects must be considered at all times.

Communications – cable termination and routing, number and configuration of drops, distances

The physical form of communications equipment is particularly noteworthy in light of the potential for difficulties arising from communications interruptions.

Operating Environment – temperature, humidity, cleanliness, vibration

The physical environment within which the equipment operates becomes a factor when operating in harsh environments. In Soloman (1994), the author examines several elements of a modern control system, and carefully examines the impact of the environment within which they are deployed upon sensor and controller function.

3.3 Improving Operator Interfaces

It seems a reasonable progression that improving automation will improve operator interfaces. Just as automation cannot completely make up for the shortcomings of the physical process, user interfaces are limited by the shortcomings of the automation. This causal chain continues beyond the operator interface – better operators often cannot overcome the failings of the interface. Since much research has focused on achieving better interfaces, it would appear that there is a need to extend the quality improvement to the next level – better automation. Automation development tools have evolved significantly, but fundamentally, the process of automation development itself has seen little concentration when considering the impact that automation quality can have on user interface design.

Given the specialized nature of the knowledge required to complete automation projects, each participant in the project contributes to the overall quality of the automation and thus the overall quality of the interface and the system as a whole.

Chapter 4
Investigation

In an effort to better understand both the success of the project and the workings of the project team, an investigation into the behaviour and interactions of the project team was carried out.

This examination was intended to draw from project team members the interactions between team members and technologies that were inherently necessary for the completion and success of the project.

4.1 Hypothesis

It is proposed that the success of the project was due to effective communication between team members, including both vendor and customer teams. Additionally, the success of the start-up was attributed to thorough process understanding and comprehensive integrated testing and commissioning.

The behaviours contributing to the thorough process understanding and effective communication exhibit characteristics of knowledge sourcing, management, and reuse, enabling team members to work together effectively and share experience.

This yields a two-fold hypothesis:

> Since implementation of this project was a success, team members will report that effective team communication and interaction were present in the development of the project, as indicated by every team member having an apparently positive effect on the overall project, measured by the number of helpful and unhelpful behaviours observed.

> Successful project deployment was supported by team members' ability to perform activities that actively assist the tasks of other team members, which will be demonstrated by specific team member comments.

Quantitative examination of the relationships between each team member will be carried out using methods of social network analysis. A secondary hypothesis applies to the social network analysis:

> It is expected that the process expert will show a strong central role in the completion of this project.

4.2 Choice of Methods

The use of interviews was chosen due to the immediate response and rich information that could be obtained. While a controlled experiment would have allowed for more explicit constraints on measurable variables, a field study examining a completed real-world project was chosen due to the availability of a non-trivial case with the opportunity to discover interactions that may not have been anticipated and tested in an experimental setting.

4.2.1 The Echo Method

The Echo Method was chosen based on the method presented in (Duimering, Purdy et al. 1998), as it was identified to be suitable as a means of capturing team interaction information in a post-hoc manner. Additionally, the Echo Method allows for an examination of the symmetry of interview responses; that is, reciprocal comments can be compared between interviewees. The method, as presented by the authors, is stated to be useful in identifying the network of both positive and negative interactions each individual encounters in completing his or her respective tasks, in a fairly "unprocessed" manner. The authors also emphasize that the method "limits the opportunities of people to say only what they think the researchers would like to hear."

4.2.2 Social Network Analysis

The volume and nature of comments generated by the Echo Method form a foundation for a closer examination of the interactions between team members. Social network analysis examines these interactions from a connectivity perspective, and in doing so, can be used to identify weak and strong links in the team structure.

In relation to knowledge management, weak links shown in social network analysis may also be weak links in knowledge transfer, and as such, possible weaknesses in the execution of the overall project.

4.3 Project Selection

Selection of the project under study was influenced by the completion of a large and successful automation project and publication of the technical details and measures of success seen in its implementation (Barsalou, McMillan et al. 2004). Additionally, project team member availability and willingness to participate, as well as subject matter experience, in combination with what was a real-world, non-trivial project, aided in the ultimate choice of this project.

Involvement of the author in the project under consideration was seen as both a benefit and a potential liability. Reservations regarding participation in the project are discussed in the limitations section of this thesis.

4.3.1 Key Project Details

The project being studied was undertaken at a major Canadian steel producer to upgrade legacy automation hardware and provide additional control flexibility. Developed by a team of personnel from both an automation supplier (the vendor) and the steel producer (the customer), the project was developed and deployed rapidly with virtually no interruption to production. The significant scale and scope of the project is outlined in Barsalou, McMillan et al. (2004).

Including elements of electrical design, control programming, extensive testing, installation and commissioning, nearly 11,000 person-hours of effort, split between vendor and customer, were spent in the completion of this project.

4.4 Interviews

Approximately four months after the completion of the project, at which time the success of the project had been established, team members were identified and asked to participate in an interview process that would examine the behaviours and interactions of the project team. The stakeholders identified from the vendor team included the project lead and technical team members. Customer team members included the project lead, technical lead, a maintenance supervisor, a management representative, and a production representative. Subjects were chosen for interview based on both availability and participation within the project – specifically, an attempt was made to contact all core team members. The time intervening between the project had the benefit of allowing project participants to see the longer term results of the project as well as subjectively distance themselves from any conflict during the project. However, as stated in Brewer (2000), some degree of forgetting was likely.

Table 1 - Interview Subjects

Abbreviation	Interviewee	Role
VPM	Vendor Project Manager	Contract and team management
VTL1	Vendor Technical Lead	Control programming
VSD	Vendor Simulation Designer	Simulation programming
VTR1	Vendor Technical Resource	Control programming, testing
CPM	Customer Project Manager	Stakeholder coordination, team management
CTL	Customer Technical Lead	Process knowledge expert
CMS	Customer Maintenance Supervisor	Scheduling of maintenance staff

4.4.1 Vendor Project Manager

The vendor project leader took on the role of coordination of communication between the vendor and customer, for both technical and business issues. This person also directed the vendor project team, assigned tasks to team members, constructed the project schedule and oversaw project execution. Additionally, an active technical role was maintained, absorbing and contributing knowledge throughout project.

4.4.2 Vendor Technical Team Members

The vendor technical team developed the project elements according to the division of work determined by the project lead. Coordination with other team members and with the customer team was necessary in order to solve problems and ensure accurate communications. Several project elements were developed, including a high-fidelity simulation of the process, control programming, operator interface changes, and data logging changes.

4.4.3 Customer Project Lead

The customer project lead worked to ensure that the vendor team worked towards the customer's ultimate goals. This person was also responsible for verification and acceptance of the work of the vendor, and communication with the vendor in both technical and business areas. Additionally, the customer project lead was responsible for coordination of the customer technical team, comprised of representatives from both engineering and maintenance.

4.4.4 Customer Technical Lead

The customer technical lead ensured that the vendor provided technical solutions that meet the requirements for form and functionality dictated by in-house technical standards. It was also necessary for the technical lead to act as a resource to the vendor technical team for technical questions and issues regarding process details as well as control equipment functionality. It should be noted that the customer technical lead was an expert resource for both the existing control system and process knowledge.

4.4.5 Customer Maintenance Supervisor

The maintenance supervisor worked to ensure that the vendor's technical solution met requirements necessary for the day to day troubleshooting and maintenance of the control system, as well as verification that the solution provided did not adversely affect the process. Additionally, coordination by the maintenance representative with customer engineering and production was necessary to schedule and complete installation.

4.4.6 Customer Management Representative

Customer management determined project goals, justified project expenditure, and (indirectly) ensured that a vendor solution was chosen to meet the goals of the project. No management representative was interviewed.

4.4.7 Customer Production Representative(s)

The production representatives (primarily operators) examined the technical solution implemented in terms of utility and usability from the perspective of a process operator. They worked to identify problems that the technical team may have discovered. One operator was responsible for the training of other process operators as to the new functionality of the technical solution delivered by the vendor. Although a production representative was contacted for interview, lack of availability prevented the interview from taking place.

4.5 Identified Team Members and Technologies

Throughout the interview process, interviewees identified several team members and technologies with which interaction was necessary to complete their part of the project. These are outlined in Table 2.

Table 2 - Team Members and Technologies

ID	Team Member / Technology (Abbreviation)
1	Vendor Technical Resource (VTR2)
2	Vendor Project Manager (VPM)
3	Vendor Technical Lead (VTL1)
4	Vendor Simulation Designer (VSD)
5	Vendor Technical Lead (VTL2)
6	Vendor Testing Lead (VTST)
7	Vendor Technical Resource (VTR1)
8	Customer Project Manager (CPM)
9	Customer Technical Lead (CTL)
10	Customer Maintenance Supervisor (CMS)
11	Customer Operators (COP)
12	Modicon Concept Programming Software
13	GE Series Six PLC

14	Wonderware HMI Software
15	Modicon Modbus Plus Network (part of 26)
16	GE IOCCM Communications Module (part of 26)
17	PICS Simulation Software
18	Customer Automation Manager (CAM)
19	Customer Electrical Design (CDES)
20	Customer Electrical Installation (CCNST)
21	Customer Automation Resource (CAR)
22	Customer Automation Supervisor (CAS)
23	Customer Technical Supervisor (CTS)
24	Modicon Quantum PLC
25	984 Ladder Logic Language
26	Communication Networks (General)
27	Customer Production Supervisor (CPS)
28	Customer Quality and Metallurgy Specialist (CMS)
29	Customer Database Resource (CDBR)
30	Equipment Supplier (SEQ)
31	Quantum Serial Communications Module
32	Vendor IT Support (VIT)
33	Customer Electrical Maintenance Technicians (CEMT)
34	SAF Drive Controller Hardware
35	Customer Maintenance Technology Group (CMTD)
36	Vendor Co-op Student (VCO)
37	Email
38	984 Ladder Logic Programming Software (used for programming 25)

It should be noted that subject 1 was the interviewer for this study, and that subject 5 was unavailable for interview as he had left the company.

4.6 Information Gathered

A set of interview questions was developed to attempt to elicit both helpful and unhelpful behaviours that team members experienced in completing the project. These questions were based on the echo method which has been identified as a suitable method for the elicitation of team behaviour information (Duimering, Purdy et al. 1998).

> Identify other team members and technologies it was necessary to interact with in order to complete this project.

In order to build a picture of the interactions required by each team member to complete their part of the project, each was asked to identify both the team members and the technologies involved in the completion of their part of the project. The inclusion of technologies also highlights the scale of the project, as well as the scope of each interviewee's involvement.

> Identify ways in which each of the other team members and technologies helped you to get your part of the project done.

Each interviewee was asked to go through the list of team members identified and highlight the helpful behaviours of each. At this stage of the interview, only helpful behaviours were discussed. Helpful aspects of the technologies were also identified.

> Identify ways each of the other team members and technologies did not help you to get your part of the project done.

After identification of the helpful behaviours, behaviours were identified that were not helpful. Interviewees were encouraged to be honest and respectful. One interviewee commented that the identification of all helpful behaviours first helped him to be more constructive and less critical when identifying behaviours that were not helpful.

> Identify ways that you helped your team members to complete this project.

> Identify ways that you were not helpful to your team members.

Interviewees were then asked to examine their performance in the project, both helpful and unhelpful. This reflexive questioning is meant to highlight any asymmetric misconceptions about the helpfulness of team members.

> What was your role in completing this project?

> In what ways were you successful in fulfilling your role in completing this project?

> In what ways were you unsuccessful in fulfilling your role in this project?

> How could you improve your performance in the completion of this project?

In order to better understand the perspective of each interviewee, they were asked to assess their own role in the project. These questions were also asked so as to provide some insight into possible disconnections between self perception and the perceptions of other team members.

> Was this project a successful project? In what ways was it successful or not?

> What were the key factors that influenced how successful this project was?

The overall success of the project was examined, in order to better evaluate the it, as well as to highlight the perspective of team members about its success.

> Is there anything that worked really well that you would do again in future projects?

As a final question, interviewees were asked to identify any specific items that they would repeat in the future. This was asked so as to elicit any highlighted or unique behaviours that may have been already mentioned or otherwise missed.

Each interview took approximately 1.5 to 2 hours, with some participants taking slightly longer. Questions were asked in an informal setting outside of the workplaces involved. Each participant expressed interest in the eventual results of the study.

Interview answers were transcribed by hand, with interviewees often explicitly seeking to ensure that the wording of their answers was to their satisfaction. Where desired, interviewees were able to review the interview transcription to ensure that they were satisfied with the accuracy of their responses.

Chapter 5

Research Results

In order to identify behaviours that aided or hindered successful project execution, seven project team members were interviewed, three from the customer team and four from the vendor team. Each was asked to list team members and technologies that it was necessary to work with in order to complete their tasks. For each team member or technology, they were then asked to indicate behaviours that were helpful to them, and then behaviours that were not helpful to them.

The interviewees were also asked to list ways in which they thought they were helpful to their team members, as well as ways they felt they were not helpful.

Each of these responses was transcribed and manually categorized for the purpose of analysis. The categories were chosen to reflect the essence of the subject's statement.

Seven project team member interviews yielded 584 comments, approximately 70% of which were indicated as "helpful". These comments were categorized by hand into general categories that were identified on an ad-hoc basis. The volume of the comments provides a rich source of information; categorization was meant to provide a gestalt impression of the nature of the comments. Specific themes in the comments are also examined, highlighting individual perceptions as well as common elements between respondents.

5.1.1 Categories

Comments were manually analyzed and categorized. The categories used were chosen so as to capture the component of the job that the comment described. Course categorization was used in an attempt to provide an indication of the areas of concern for the individuals involved, in a manner similar to that proposed in Duimering, Purdy et al. (1998).

Categories were developed based on the comments; if a comment did not appear to fit in a specific category, a new category was added, or an existing category may have been revised. The categories identified are outlined below. This method of categorization can be viewed as "open coding", as outlined in (Burnard 1991), where interview responses are examined and categories constructed and refined based on the interview contents. The method presented by Burnard includes additional categorization by colleagues, as a method of verifying the categories derived. For the purposes of this study, the categories have not been independently derived. Automated methods of automatic categorization, such as those presented in (McGreevy 1995) have not been explored, given the moderate volume of text involved.

Job Task – this category was used to describe specific items or actions that would be carried out as a part of a team member's job. Positive comments regarding job task would be indicative of the team member or technology fulfilling a job role, as well as completing specific tasks to further the project. Negative comments would indicate areas where the job role was not fulfilled, or areas where a task was not completed. An example of a comment in this category is "Did HMI screens".

Job Role – this category was used to describe broad or general statements regarding the responsibilities a participant had in the overall project. In general, positive comments regarding job roles should be indicative of good overall performance and success in most job tasks. Negative comments regarding job role would indicate areas where the team member may not have completed the tasks undertaken. An example showing the job role category is “Picked up more work – initially was only supposed to be minor – helped when schedule was slipping”.

While the division between role and task is somewhat arbitrary, the relationship between the two supports the division between the two categories. Typically the comments in these two categories support each other; that is, performance in a job role is related to performance in a job task and vice versa. However, it is possible to fulfill a role well but fail to perform on specific tasks, or to perform tasks well but fail to fulfill the complete responsibilities of a job role (although more often this would be seen as a corresponding failure of job tasks).

Declaration – this category includes specific statements that are descriptive and not related to specific behaviours or tasks. This category reflects the interviewee’s subjective opinion about the topic under discussion. Since these statements were not backed by specific behaviours or tasks, it was necessary to categorize them separately from behaviour or job tasks. A good example of a declaration is the statement that a team member was “just fabulous”.

Behaviour – this category was chosen to contain comments describing the manner in which the job role was fulfilled. Behaviours apply to more than specific job tasks, rather they are descriptive of overall working tendencies. For example, “narrow focus” was seen as unhelpful.

Characteristics – descriptions of team members as related to specific job tasks or job roles. This is distinct from behaviour in the fact that these may not apply to a task. Example: “saw project as a whole”.

Performance – indication of the ability of the team member to deliver results. Performance is related to both job tasks and job roles; successful performance would indicate successful completion of job task and fulfillment of job roles. Example: “Code worked well”.

Knowledge – in general, indication of the specific domain knowledge the team member brought to the project. Given the highly specialized domain knowledge involved in this project, leveraging team member knowledge was often necessary. In an exploration of knowledge, Kakabadse, Kouzmin et al. (2001) outline elements of knowledge that stem from experience and are hard to communicate with others. This “tacit” knowledge is often related to the context of the problem at hand. In this regard, formal transfer or recording of this knowledge can be challenging. In a very philosophical paper, Blosch (2001) develops many conclusions, most notably, “It is people who have knowledge and not information systems.” Illustrative of this category is the statement “Technical Guru on how it works”.

Communication – items related to the team member’s tendency to share information related to the task. This category is closely related to knowledge in several ways. Specifically, improved communication implies improved transfer of knowledge. Additionally, high levels of knowledge between team members allows for more efficient communication within the context of the project. An unhelpful example of this was “Asked questions repetitively”.

Management – comments related to team and project management. With the large project team involved, management issues transcended the bounds of the project itself and thus included political struggles, in addition to relationships between customer and vendor teams. An example of this is “Sometimes got mired in internal issues”.

Capabilities – this category was used to highlight comments indicating the capabilities (or lack of capabilities) of team members or technologies. While negative comments regarding capabilities may indicate a negative impact on project success, it is possible that lower capabilities go hand in hand with less demanding job roles. A specific example is “Lower skill set”.

Availability – this category contains comments related to the availability or lack of availability of team members. Since there was a great amount of domain knowledge involved in this project, lack of availability of subject matter experts would reduce the effectiveness of the project team. The work of Jarvenpaa and Leidner (1999) indicates that “substantive and timely response” contributed to the overall trust of team members in each other and to the success of a project team, even across geographically separate locations. This can be seen in the comment “Busy with other projects (hard to get a hold of)”.

Failure – this category is used to contain comments that indicate failure of team members or more often technologies to perform necessary tasks. In general, only technologies exhibited outright failure. By definition, this category contains only negative comments. An example of this category, with respect to a technology (software) is “Issues with online downloading”.

Social – this category contains statements that were related to the interpersonal elements of the project. Given the large project team, social interactions were frequent. However, there were few comments in this category. While this category may not be directly related to project execution, the work of Jarvenpaa and Leidner (1999), showed that positive social communication facilitates trust between team members. Additionally, social aspects of the project are not necessarily unrelated to performance, as seen in the comment “Added tension during commissioning”, which has been categorized as a social comment.

5.1.2 Typical Comments

Without some context, the example comments may lack the detail necessary to fully understand the implications of each, especially where the comments are about technologies rather than team members. However, the typical comments do reflect the general character of each category. Closer examination of specific categories and comments provides the context lacking in the list of typical comments.

The results may be summarized to several different levels of detail. At the highest level, the total number of helpful behaviours can be compared to the total number of behaviours that were not helpful. Of 584 comments, 408 were helpful, and 176 were unhelpful.

The ratio of helpful and unhelpful behaviours may show some bias on the part of the interviewees towards giving more helpful responses than unhelpful. In light of this, each respondent’s ratio of helpful to unhelpful comments cannot be directly compared to other interviewees without some manner of normalization. Additionally, interviewees may have been tiring of the interview process, and thus given fewer unhelpful comments. However, in the technologies identified, no positive tendency was seen.

In addition to the Echo Method questions asked in the interview, each interviewee was asked follow up questions in which they provided background regarding their role in the project, an assessment of their performance in the project, and an assessment of the overall success of the project. Additionally, they were asked to identify key factors in the success of the project, as well as any techniques or methods they would use again in future projects. The follow up questions are presented in section 4.6, along with the echo questions.

The follow-up questions were intended to provide context for the respondent's comments, as well as to examine the correlation between their assessments of the project and the helpful and unhelpful behaviours identified by each. Interviews typically took between one and two hours, although in some cases interviews took longer. The variability in interview times may be related to each interviewee's involvement in the project, in addition to individual comfort in responding to interview questions. Additionally, since each interviewee identified a unique set of team members and technologies, some interviewees identified and discussed more subjects than others.

In general, responses indicated that the project as a whole was viewed as a success, with some reservations. Areas in which the project was less successful varied depending on interviewee, with some common elements divided between customer and vendor interviewees. Specifically, from the vendor perspective, the project was not completely successful due to the departure of a team member after the project ended. From the customer perspective, the success of the project was affected by support and maintenance concerns.

The overall success of the project was also attributed to factors outside of the scope of the project team. Specifically, a part of the overall success of the project was attributed by one team member to the fact that the fundamental goals of the project were valid. Had project execution been perfect but the end result not be capable of satisfying the financial motivation for the project, the success of the project would be tainted, no matter how well the execution had occurred. For a complete examination of the costs and benefits of the project, see Barsalou, McMillan et al. (2004).

5.1.3 Ratios by Category

The greatest number of comments were seen in the job task category. This would seem reasonable, given a well structured project team; the completion of job tasks by other team members should in many cases directly affect the performance of other team members. As seen in Figure 4, for most comment categories, the majority of comments were helpful.

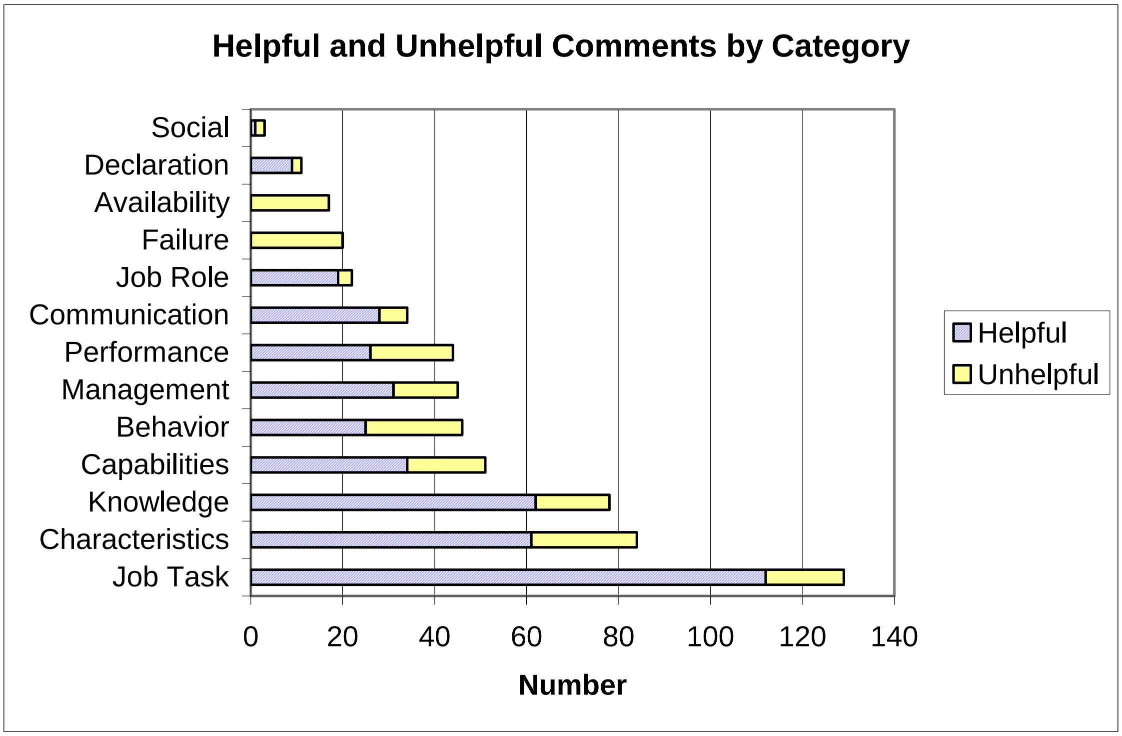


Figure 4 - Comments by Category

It is interesting to note that comments regarding availability are all unhelpful; that is, availability was not ever identified as a way in which the job was helped, only as a way the job was hindered. This may imply that a baseline availability was necessary, below which the lack of availability was a hindrance, above which was acceptable but not specifically helpful.

It should also be noted that failure is by definition an unhelpful category. Additionally, the majority of failure comments were technology related.

To give some perspective on the number of comments generated by each interview, Figure 5 presents a graphical representation of each subject's helpful and unhelpful comments. As a percentage, the number of helpful comments given by each interviewee ranged from approximately 53% to 80%, and interviewees provided a minimum of 51 and a maximum of 136 total comments. The Customer Technical Lead (CTL) and Customer Project Manger (CPM) each provided more than 120 comments, likely related to the large and central role played by each in the execution of the project.

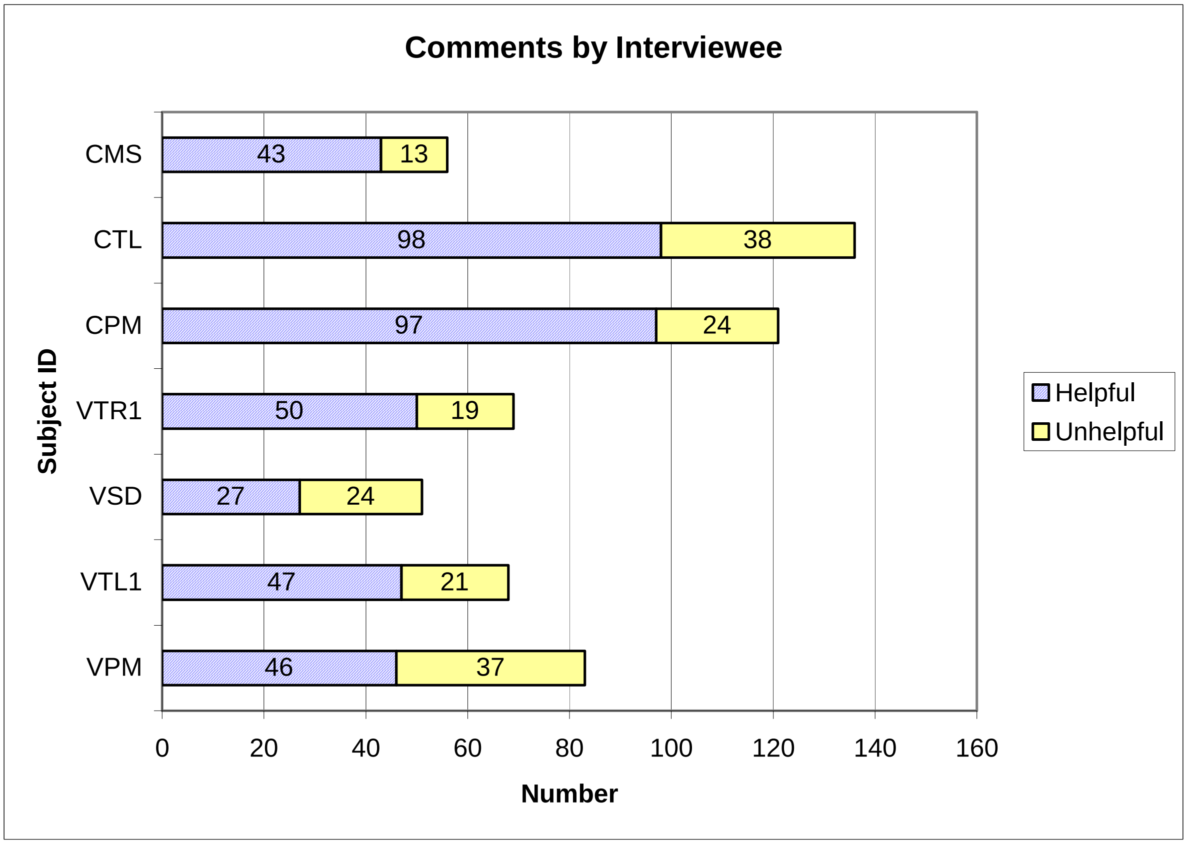


Figure 5 - Comments by Interviewee

A total of 38 team members and technologies were identified as playing a part in the completion of the project. To show the relative frequency of comments about each of these, Figure 6 presents a chart for each team member or technology identified, collapsed across all interviewees. A description of each subject ID can be found in Table 2.

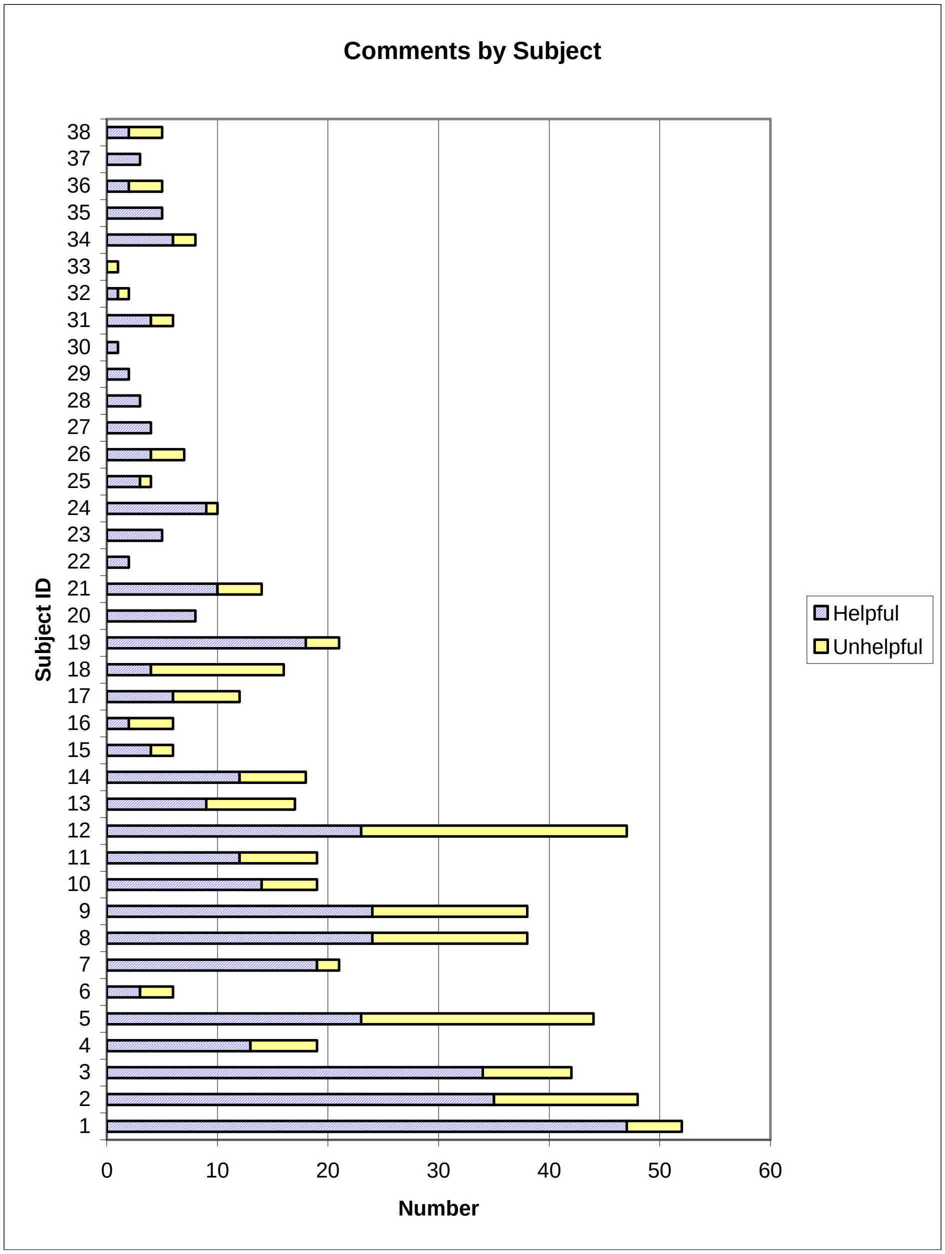


Figure 6 - Comments by Subject

5.2 Common Themes

Certain themes emerged both within individual interviews and across multiple interviews. These common elements merit further examination.

Knowledge

Multiple comments were made as to the degree of technical knowledge possessed by team members. For example, one team member was identified as the "technical guru" for existing process and electrical operation. Other team members were also cited as sources of knowledge or experts in specific areas of system operation. It was necessary to use the team's "collective knowledge" to develop the complete solution – the result of team members having "compelling reasons" both to share information and to seek information. (Ruddy, 2000). Much of the information exchanged was informally transferred through collaborative work, meetings, conversations, and email. Additionally, technical manuals and electrical drawings were used. In a manner similar to the distributed cognition identified by Hutchins (1995), team members appear to have attempted to leverage the knowledge, experience, and capabilities of each other in the completion of their respective tasks.

It is also interesting to note that in some cases, knowledge was cited as an unhelpful characteristic. Specifically, it was indicated by a team member that the greater initial process knowledge held by process experts from both the vendor and customer was a hindrance since it lead to poor communication, and that information was harder to convey to new people who did not have mastery of the same jargon or technical language. This same respondent had also indicated knowledge as a helpful element as well. Conceptually, this might arise from the thought that:

> "Knowledge can be transferred because the individuals between whom it is transferred have a rich set of mutual understandings – they share a great deal of tacit knowledge that they use to interpret (make explicit) the explicit knowledge." (Wensley 2001)

Further to this, different organizations (as is the case with this project, with vendor and customer teams having varied backgrounds) often do not share the same set of tacit knowledge, possibly making it difficult for less experienced team members to integrate information and express concerns.

Communication

Along with knowledge, communication seemed to play a major role in the completion of the project, from both a team interaction and knowledge transfer perspective. In terms of team interaction, reporting of status between team members was seen to be helpful in some cases, and lack of accurate reporting was appropriately seen as not helpful.

With regards to transfer of knowledge, there was indication that knowledge seeking may have been ineffective by some team members. Specifically, unhelpful comments included "asked questions repetitively" and helpful comments included "don't have to explain 3 ways".

Availability

The availability of team members was not ever indicated as a helpful item. This would seem to imply that a baseline of availability was normally achieved, although sometimes that availability was lacking. Alternatively, it could be proposed that ideal availability is rarely, or possibly never, achieved. It is interesting to note that the customer technical lead that had been identified as "technical guru" was also indicated to be unhelpful due to availability, and also indicated in the follow up questions that he would improve his performance by making himself more available.

Performance

Several comments indicated appreciation for the ability to work hard and get the job done. While project success would seem to be necessarily related to good performance, it is interesting to note the language used to describe it: "would really dive in", "likes to get in, figure it out, and get it right", "dug into it". This would seem to relate to the levels of organizational maturity outlined in Section 2.4.1 – highly competent people are appreciated for their contribution to the success of a project.

Confidence

Multiple comments indicated a degree of appreciation for team members' confidence in contributing to discussions and completing their assigned tasks. The lack of confidence was also seen as an unhelpful characteristic, seen in the comment "seemed to lack confidence in programming".

5.3 Notable Comments

In addition to the recurring themes, some comments stood out for the sentiments expressed, which were sometimes unique, and sometimes repeated.

"It's not my problem" – cases where team members took this viewpoint were identified to be a problem, and where team members were unlikely to take this perspective, it was seen as a specific helpful behaviour.

Progress Assessment – in more than one case, this was identified as a deficiency of project team members, whether with regards to absolute completion or degree of progress along the project schedule as a whole. This was also seen as an issue of communication between the vendor and customer. An example comment indicated that a team member "failed to notify project lead of status as project neared end – needed to say he was behind".

"Asked questions repetitively" – the effectiveness of communication in a large distributed project team can be lessened by low quality communication (Jarvenpaa and Leidner 1999), resulting in a reduction in trust of team members. Hand in hand with concerns about repetitive questions was a comment expressing concern that the type of questions asked "tended to indicate that he lacked understanding".

"Created atmosphere – we want to get this done, and done right". Similar to ideas found in the work of Reilly, Lynn et al. (2002), team members saw benefits in both the conscientiousness of team members, as well as team members' ability to encourage a conscientious attitude in the rest of the team. The concept of atmosphere was also seen in negative terms on occasion as well – comments indicating that team members at times felt "scolded" or felt that other team members added stress to the situation. However, it should be noted that general agreeableness is not necessarily a predictor of performance or productivity (Kichuk and Weisner 1997), although it is seen as a positive characteristic in social tasks, such as training. General agreeableness is also seen as a part of avoidance of interpersonal conflict, which is seen to be beneficial.

5.4 Unhelpful Aspects

Examination of the unhelpful comments seems to show that interviewees had a tendency to state specific unhelpful aspects of technologies, whereas they stated unhelpful aspects of team members in more general terms.

Specifically unhelpful aspects of the technology tended to focus on unpredictable behaviour and lack of functionality. For unhelpful team member behaviours, comments were either phrased in general terms, or referred to specific incidents, but lacked further context of the incident.

5.5 Technology

It seemed that interview subjects were more willing to express negative opinions about technologies than about team members. Whether this is due to bias, or to relative capabilities of team members in comparison to the technologies used is unclear. There was possibly some reluctance on the part of interviewees to criticize team members, in addition to concerns as to the eventual destination of interview results. For all comments regarding technologies identified 42% of the comments were in the unhelpful category, whereas for team members, 26% of the comments were unhelpful.

By far the most comments were regarding the PLC programming software called Concept (47 comments, comprising 32% of the technology related comments). This software package was essential to the completion of the project, as it was the means by which the process control programming was written and modified. It seems notable that approximately half (51%) of the comments regarding this software indicated that it was not helpful to the interviewee. Specifically, there were concerns with bugs, crashes, and unpredictable behaviour. While other technologies also received similar percentages of comments indicating the technology was not helpful, no other individual technical subject received even half the number of comments.

5.6 Opinions of Project Success

In addition to the financial aspects of project success presented in Barsalou, McMillan, et al. (2004), interviewees were asked whether or not the project was successful, and in what ways. The general consensus was that the project was a success, with five of the seven interviewees citing no unsuccessful aspects, considering that the project was on budget, delivered in a very short time frame, and met the fundamental objectives, allowing for significant cost savings.

However, there were unsuccessful elements identified as well. Specifically, two significant aspects were identified; insufficient customer resources for troubleshooting intermittent issues, as well as the departure of a member of the vendor team. The lack of customer resources was attributed to being unable to focus on the project throughout development. From the vendor perspective, communication was cited as both a factor influencing success, as well as a negative influence where poor communication was present.

Success was attributed to a variety of factors, including a “very skilled team”, the fact that team members “used individual skills to support each other and the project success”, and a “very knowledgeable team.” One interviewee also noted that the ultimate success of the project was also due to the fact that ultimately, the process changes facilitated by the project worked as planned, providing significant cost savings.

5.7 Social Networks

The interactions between interviewees develops into a social network that highlights different paths of information flow throughout the project team. Since significant interaction occurred between many members of the project team, it was useful to plot these interactions to get an overall image of the connections between team members. Social network theory examines the structural properties of groups in various organizations and in some cases attempts to examine how these networks affect group performance (Cummings and Cross 2003). While detailed mathematical analysis of the social network is beyond the scope of this thesis, preliminary examination of the general patterns in the social network provides additional insights.

A diagram built using the interview results, shown in Figure 7, highlights the great degree of interdependence between both the customer and vendor project teams. It also shows the relative number of comments by each subject about each of the other team members mentioned in the interviews.

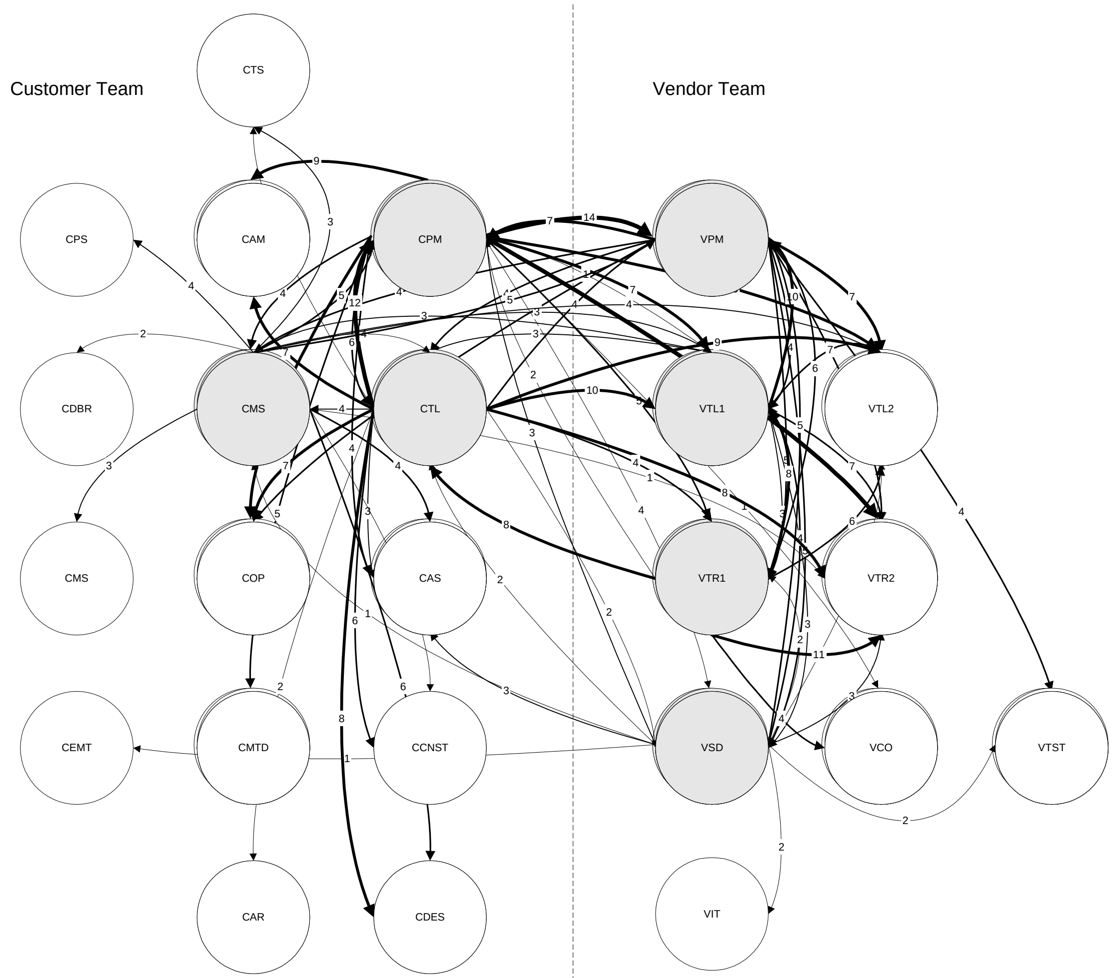


Figure 7 - Team Interconnections.

Note that in Figure 7 the grey circles indicate the core team members that were interviewed, and that the relative line weights indicate the number of comments the interviewees made about each subject. The general arrangement of the circles has the customer project team on the left and the vendor project team on the right, with the project team members generally arranged with the project managers at the centre top and the other project team members arranged around the project managers according to responsibility within the project. Consistent with the findings of Han (1996), who states that work is "carried out through interactions with coworkers, superiors, subordinates, customers, and countless others," the emergent network is influenced by the formal chain of responsibility in both the customer and vendor organizational structures, with some degree of hierarchical interconnection evident between project management and subordinates, similar to an organizational chart. Both the vendor and customer project managers have many connections to both each other and the respective project teams. Additionally, interconnections across the vendor and customer teams are seen between technical leads.

The peripheral connections reflect the fact that several project team members acted as resources internal to either the customer or vendor project teams. The greatest degree of interconnection is seen between the project managers and both technical teams. The vertical dimension loosely correlates to scope of responsibility in the overall project.

The work of Kadushin (2002) outlines the consequences of the degree of connectedness found in a social network. Specifically, cohesion (connectedness) in a network is said to be supportive of team performance, while lack of connection is seen as supporting competition within the network, as the value of a team member's connections is raised by the fact that the team member can form a bridge to other resources, and use that to gain advantage over other team members.

Figure 7 also illustrates the weaknesses in coverage for the set of interviewees chosen. Given the degree of interaction with other members of the team, two additional vendor team members would seem to be useful interview subjects. However, one key team member left the organization (VTL2) and declined to be interviewed, and the other is the author of this thesis (VTR2). On the customer side, a representative from the group of operators was approached with the interview questionnaire, however, no response was received. Additionally, another team member with some involvement retired from the organization shortly before the completion of the process.

In the context of overall team success in complex non-routine work, Cummings and Cross (2003) state that integrative, or well-connected, social structures result in higher performance, as sufficient ties support information flow and the spreading of "unique expertise". However, caution is raised as to the prospect of over-reliance on a single team member.

In light of the danger seen in over-reliance on a single team member, and in the context of the team member in this case identified in interviews as the "technical guru" (CTL) for both the process and the technology, it is expected that the technical guru will show a measurably central role in the overall project team. Potentially, the removal of a node in the network may result in the disconnection of different areas of the network, in which case a "structural hole" is said to exist

However, the removal of any single core team member would have had significant impact on the completion of the project from a division of labour perspective; while technical team members can generally be replaced, subject matter experts (or knowledge sources) and team members in brokerage roles (that is, situations within the social network that are intermediate connections between otherwise unconnected segments) are harder to replace by virtue of both the "unique expertise" held, as well as the interconnections present.

By virtue of having management roles, the two project leaders have some degree of brokerage of the connections between the customer and vendor project teams. However, the other non-hierarchical interconnections of the technical team enhance overall performance and reduce reliance on the project leaders for knowledge transfer (2003).

5.7.1 Social Network Measures

Mathematical analyses of social networks have attempted to quantify social network interactions in order to better assess the characteristics of social networks, as well as to allow for comparisons between differing social networks (Scott 1991). A variety of measures and mathematical analyses exist, providing insight into the characteristics of these networks, but are sometimes of uncertain significance.

Fundamental to the examination of social networks is the concept of connectivity between two nodes (people) in the network. Using the responses obtained from the interviews conducted, the relative strength of relationships between team members can be examined.

A matrix was constructed indicating the connections between each team member, with the interviewees arranged in the rows, and the subject of the interviewees' comments arranged in the columns. Each cell in the matrix is then filled with the number of helpful and unhelpful comments made by the interviewee about each subject. This is then an incidence matrix that is both valued (connections are weighted by the number of comments) as well as directed (strengths are measured from rows to columns, resulting in an asymmetric matrix).

While several variations of social network measures exist, a few fundamental measures form the basis for mathematical analysis of these networks.

Density refers to the "connectedness" of a network. A network that is more connected is more dense than a less connected network. For binary networks (that is, networks that only have presence or absence of connections), measures of density relate the number of connections in a network to the total number of possible connections that would be possible. With valued connection data, meaningful calculation of density requires the use of methods that normalize or dichotomize the connection data.

Centrality refers to measures of positional significance within social networks. Including the concepts of "closeness" and "betweenness", measures of centrality seek to determine the relative importance of the role a member of a social network plays. Many methods of calculating centrality exist, taking into account the type of data present, as well as attempting to provide a meaningful comparison between differing social networks.

One simple measure of centrality is the calculation of the degree of actors in a social network. For binary networks, degree is the summation of connections for each actor. For valued networks, degree is the summation of the weights of each connection for a particular actor. For directional networks, two measures of degree may be calculated; "in" degree and "out" degree, reflecting the direction of connections for each actor.

For the interview data collected in this study, each comment made by interviewees has been counted in order to tabulate a weight of connection for each interaction in the network. The "in" degree, that is, comments made about each actor, provide a measure of views held by each team member about each actor in the network. The "out" degree measures the total number of comments made by each team member.

Dichotomizing the network link data converts the valued link data into binary relationships, indicating only that a link or no link is present. In order to dichotomize the data, it is necessary to choose a threshold at which point a relationship is strong enough to be considered a link.

Of some interest in the overall performance of the team is the net helpfulness, as indicated by the difference between the number of helpful comments about a team member, less the number of unhelpful comments. While not intended to be an assessment of each team member, it appears to be a useful consideration when examining the strength of helpful behaviours seen for each connection. The estimation of net helpfulness provides a different method for the elimination of marginal actors from the network, capable of removing connections rather than removing actors by isolating nodes, as was seen when attempting to use a threshold to dichotomize the data.

Calculation of "net" helpfulness is used instead of normalization of interview results in an attempt to accommodate varying levels of responsiveness of interviewees without losing the relative weight of connections given by the number of responses. As an example of this effect, consider the two cases shown in Table 3, where the number of comments given by two team members about another team member are shown.

Table 3 - Net Helpfulness Example

Interviewee	Helpful	Unhelpful	Net Helpfulness
CPM	4	4	0
VTR1	5	1	4

In the case illustrated in the table, both the customer project manager and the vendor technical representative identified the same team member as a necessary individual involved in the completion of their respective roles in the project. While both interviewees provided a similar number of comments indicating helpful behaviours (4 and 5), it can be seen by the net helpfulness calculation that the team member in question was in some way more helpful to the vendor team member than to the customer project manager.

While this "Net Helpfulness" calculation is somewhat naïve in weighting each comment equally, it was found to be a useful method of accommodating the varying number of responses given by each interviewee, allowing for comparisons of the strength of helpful relationships between team members without assuming that all team members were equally involved in the project, as normalization would imply. In the case presented in Table 3, it can be seen that even though the customer project manager made more comments overall, a stronger helpful relation exists with the vendor technical resource.

Calculation of the net helpfulness of every team member yields a network where twenty-three of the twenty-five identified team members are connected to the graph, as shown in Figure 8. The network shown depicts all connections where a net positive helpfulness was found, regardless of connection weight.

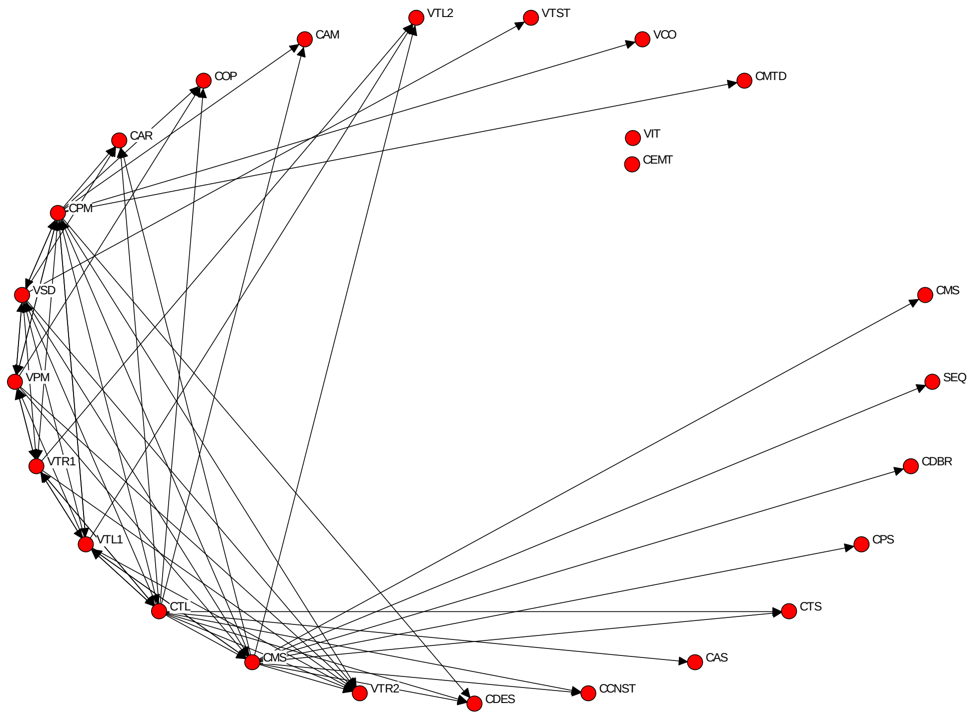
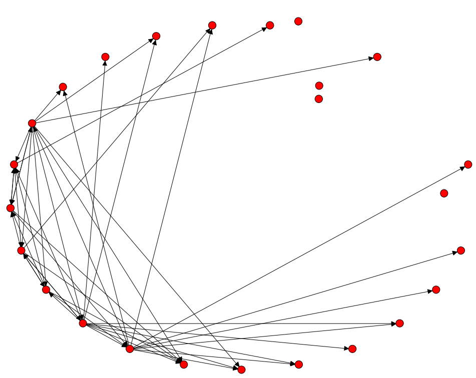


Figure 8 - Helpfulness Network

In order to better understand the weight of the connections in the network, it can be useful to show the same network with different thresholds used for the dichotomization of the data (that is, different thresholds used to determine whether or not a connection is present).



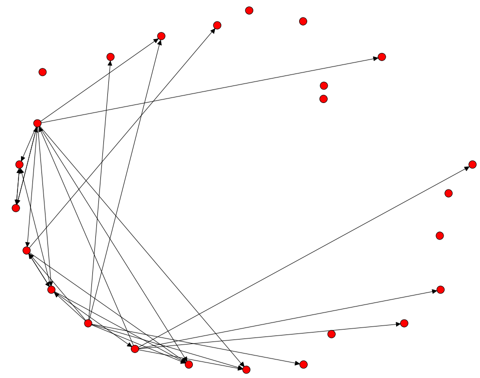
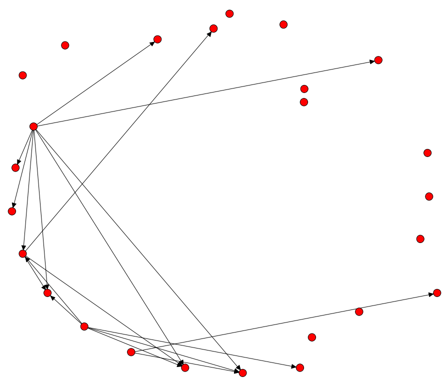


Figure 9 - Threshold Level One **Figure 10 - Threshold Level Two**



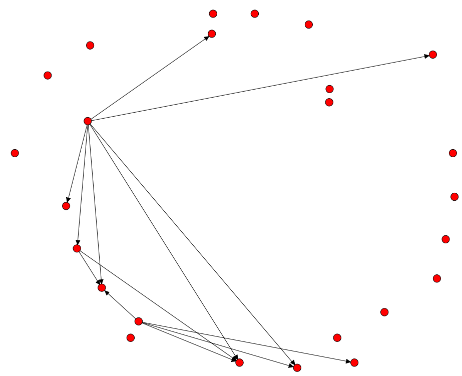


Figure 11 - Threshold Level Three **Figure 12 - Threshold Level Four**

At each threshold, several team members become disconnected from the network. Table 4 shows the number of connected nodes found at each threshold. At a threshold of four, the weight of all remaining connections in the graph is five or greater, indicating a relatively strong helpful relationship existed for each of the remaining connections. It is interesting to note that no isolated sub-networks are created in this process; it could be argued that this indicates that the team as a whole operated in a well connected manner, with no sub-group operating on its own. In the case of a vendor and customer relationship, this would seem to be a useful finding, showing that the vendor and customer teams operated together, working towards a common goal. Note that in Figure 12 the arrangement algorithm has caused some of the points to move slightly, but the general shape is consistent.

Table 4 - Connected Nodes and Thresholds

Threshold	Connected Nodes	Disconnected Nodes
0	23	2

1	21	4
2	17	8
3	14	11
4	10	15

Many mathematical measures of social networks are often used in order to compare differing networks, as is the case in the calculation of network density, which is a measure of the overall connectedness of a particular network. Other measures can be used in evaluating the roles of elements of social networks, for examination of single networks.

For the purpose of this examination, the Degree Centrality can be used to evaluate the helpfulness of each team member to the overall team. Since the data is directed (that is, comments are by one team member about another), only the "In" degree is useful, as that summarizes the helpfulness of each team member in the views of the other team members. For the calculation of centrality, the software UCINET (Borgatti, Everett et al. 2002) was used.

Table 5 - Team Member Centrality

Team Member	In Degree Centrality
VTR2	42
VTL1	24
VPM	20
CDES	17
VTR1	15
VSD	12
CPM	8
CMS	8
CCNST	8
CAM	8
CAR	6
CTL	5
CMTD	5
COP	5
CTS	5

CPS	4
CMS	3
CDBR	2
CAS	2
VTL2	2
SEQ	1

The rank of the centrality scores shown in Table 5 present interesting results. The first item of interest is that five of the top six most "central" team members are vendor team members. Additionally, the highest ranked customer team member is the Customer Design representative. This may be a result of the volume of work accomplished by these team members.

Additionally, the Customer Technical Lead (CTL), acknowledged by other team members to be the technical "guru" in terms of system operation, does not rank in the top ten most central team members. Given the acknowledged expertise of the Customer Technical Lead, this is somewhat surprising. However, this is in line with interviewee comments, both by and about the Customer Technical Lead, indicating that improved availability would have been useful.

Chapter 6
Conclusions

With the complexity of a large automation project there arises an inherent complexity in the interactions between members of the project team. As such, examination of these interactions was undertaken to better understand the role project team interactions play in the successful deployment of a large automation project, as well as areas where these interactions can be improved.

Through the use of an interview process that can be referred to as the Echo Method, the interactions of core project team members were elicited, with a specific division between helpful and unhelpful aspects of these interactions. Additionally, team members' interactions with technology were examined.

It was found that the majority of interactions between team members could best be classified as interactions related to the job task being undertaken. As would be expected with a successful project, the majority of the comments in this category indicate helpful interactions between team members.

In assessing areas where team interactions could improve, team member availability was identified as an area where all comments indicated that lack of availability hindered team performance. Since the subject matter for automation projects is often highly specialized, team member availability may have an impact on other project team members, as the specialized knowledge held by the unavailable team member may be useful or even essential to other team members.

Examining the individual elements of the hypothesis proposed in light of the interview results yields some conclusions regarding the workings of this project.

> Since implementation of this project was a success, team members will report that effective team communication and interaction were present in the development of the project, as indicated by every team member having an apparently positive effect on the overall project, measured by the number of helpful and unhelpful behaviours observed.

While the majority of comments were seen as helpful, it is not clear that this is due to truly helpful interactions, or only due to positive bias on the part of the interviewees. When examining the specific comments related to communication and knowledge, 82% of communications comments were helpful, and 79% of knowledge comments were helpful. However, in the follow up questions, the only negative factor identified regarding project success was "lack of communication / poor quality communication".

> Successful project deployment was supported by team members' ability to perform activities that actively assist the tasks of other team members, which will be demonstrated by specific team member comments.

The category with the largest number of comments was the job task category, containing comments pertinent to team members' execution of specific duties within the project. However, the comments do not show general characteristics indicating that team members "actively assist the tasks of other team members", with the exception of occasional comments indicating that team members helped or assisted one another.

Specific comments have indicated that the "it's not my problem" attitude is seen as an unhelpful behaviour or interaction within the project team, and that team members who were not prone to this attitude were seen as very helpful. While no pattern was seen in the number of comments indicating this, it does offer weak support of the second element of the hypothesis.

A more evident trend in the comments was found in the proportion of helpful and unhelpful comments seen in regards to team member availability. In light of the specialized knowledge inherent in the project, as well as the acknowledgement of specific team members as critical to the project for that specialized knowledge, lack of availability could be seen as a major concern in project execution.

> It is expected that the process expert will show a strong central role
> in the completion of this project.

With regards to the utilization of expert knowledge within the project team, centrality measures and team member comments indicate areas where team members did not actively assist each other in the completion of tasks to the extent that was desired. Specifically, poor team member availability was seen to be a hindering behaviour, reflected in comments made about multiple team members, as well as identified as areas for self-improvement by the team member acknowledged to be the "technical guru" and subject matter expert by other team members. The relative rank of the technical expert in centrality measurement did not reflect the team member's central role as a knowledge source, and may highlight a weak point in the execution of this project.

6.1 Discussion

Single case study analyses offer weak generalizations about the domain under study. However, some of the insights obtained may be immediately useful in practice, even though conclusions may not necessarily be extended beyond the individual case study.

Given the degree of interaction required by a large project team, as well as the complexity of the subject domain, team member availability and knowledge transfer (or lack thereof) are believed to be important to other team members. While a controlled examination of this impact is not possible, it may be possible to assess the specific effects of lack of availability in future projects as they are executed. In this manner, the impact may be quantified in terms of delay or other explicit impact.

As examined in Gray and Meister (2004), behaviours attempting to obtain information from others, termed "Knowledge Sourcing" by the authors, are used by members of an organization as an attempt to compensate for deficiencies in personal knowledge. Among the related concepts identified, seeking information from others, as well as seeking help from others, demonstrate the reciprocal relationship to the relationships identified in the interview process undertaken for this study.

Specifically, interviewees were asked to identify helpful behaviours, and among the helpful behaviours identified were both the knowledge of others and specifically helpful tasks performed by others. To further examine team performance in the context of Knowledge Sourcing identified by Gray and Meister, it would be necessary to ask each subject about specific information seeking behaviour carried out in the process of fulfilling their respective roles in the project.

However, the identification of sources of knowledge was evident in the comments made by interviewees. Approximately 13% of the total number of comments were categorized as knowledge related, crediting other team members as sources of process and technical knowledge. According to the definition outlined by Kim, Hwang et al. (2003), knowledge is “expertise, skills, know-how, and experience” and can be categorized as being general knowledge, system knowledge, or domain knowledge.

The authors go on to outline other levels of knowledge types and depths, strongly supporting their assertion that much knowledge is gained through years of experience, and may exist solely in the heads of team members, an insightful perspective given the responses of interviewees in this study, including comments such as “should write things down” and “sometimes forgetting things”. While the focus of the work by Kim et al. is restricted to the execution of manufacturing, as opposed to automation development, the nature of process knowledge identified in manufacturing seems relevant to automation development as well. The authors explore knowledge flow analysis from the perspective of the parties involved in the operation of an operating facility, breaking down the process into areas of expertise similar to those necessary in automation development, namely mechanical, electrical, instrumentation, computer, and control knowledge.

The inclusion of a team of vendor personnel raises the importance of the flow of knowledge from customer to vendor team, due to the fact that members of the vendor team need access to the range of experience and knowledge identified in many, if not all, of the sub-categories identified.

The interaction between customer and vendor teams is further complicated by geographic constraints, creating to some extent a “virtual” team, in the parlance of Jarvenpaa and Leidner (1999). As such, care must be taken by all project team members to ensure that communications are frequent and timely, in order to support team members’ information needs, as well as to engender trust among team members.

From an organizational perspective, and a team perspective, the work of Bhatt (1998) raises an interesting point. Specifically, the author states that “An organization is not an exclusive artifact of technological systems. It is also an artifact of personal experience and social relations.” The implication of this is also stated, namely that “semantic and pragmatic knowledge” are difficult to formally capture. In the automation development process, much of the information required is tacit and experiential (2003), necessitating team member interaction, and requiring, from the perspective expressed by Bhatt, flexibility and personalization.

From a cognitive perspective, the computational aspects of a team, as presented by Hutchins (1995) illustrate the fact that a team with common goals operates in a manner similar to a parallel computer, taking advantage of the capabilities of team members to deliver results flexibly and reliably. Given this model, the effectiveness of team members relies on the memory and communications capabilities of the team, as well as the ability of team members to assist other team members by the identification and correction of error, as well as assisting with tasks beyond each member's defined scope.

Similar to the computational error correction identified by Hutchins, where team members sometimes assisted others by going beyond defined roles, interviewees expressed comments indicating that the viewpoint "it's not my problem" is detrimental to team performance, and that team members who do not take this viewpoint aid in the eventual project success. In Hutchins, this is made clear by the case where crew members both correct each other and assist each other in completion of navigational tasks, even though a prescribed set of duties is identified for each member of the team.

When automation development is considered as a social system, as navigation has been in Hutchins and as problem gambling has been in Burns and Hajdukiewicz (2004), development team members form a key component of the system as a whole – that is, not only are they developing an automation system, they are also actors in the system as a whole. While this study has not attempted to treat development team members explicitly as components of an automation delivery system, the attention paid to knowledge transfer and helpful behaviours takes first steps towards examining the interactions of team members as such a system.

6.2 Implications for Design

The complexity of a large scale automation project presents several challenges from many perspectives. Due to the specialized knowledge inherent, and the wide range of skills of the project team, helpful interactions between team members can be seen as vital components in the delivery of high quality automation. The output of a team may be greater than the sum of the capabilities of individual team members (Hutchins 1995), due in part to team members' abilities to leverage the knowledge, experience and capabilities of other team members, as well as the mechanisms for correction and adaptation inherent in the structure of a team, where varying levels of experience provide both complementary and overlapping capabilities.

In assembling a design team, it is a trivial conclusion to state that it is necessary that the full complement of capabilities required must be present (or obtainable) within the team assembled. However, in light of the value of experience presented in Kim, Hwang et al. (2003), as well as Hutchins (1995), in addition to the value of overlapping capabilities shown by Hutchins, it becomes apparent that areas of overlapping capabilities support team flexibility, and contribute to the overall quality of team performance.

Interviewees identified multiple team members as sources of knowledge and learning resources. In the completion of the automation project considered in this study, it could be proposed that the success of the project was in fact supported by overlapping capabilities as outlined by Hutchins, in addition to other factors. The relatively low centrality rank of the commonly acknowledged domain expert may indicate that a degree of domain knowledge overlap existed, allowing team members to obtain information from other resources where necessary.

6.3 Limitations

It must be noted that this is only a single case study, carried out after the completion of a single large scale (approximately 11,000 person hours) project. Additionally, the interviewer was a participant in the project, with the role of vendor technical resource.

The nature of an interview situation may also influence the degree of candidness shown by interviewees. Areas of concern include the possibility of biases towards positive responses, as well as interviewee concerns regarding misinterpretation of comments. Additionally, the participation of the interviewer as a technical resource in the development of the project may cause some degree of bias in interview respondents, although participation in the project may have yielded benefits in terms of team member access and comfort, as well as background in the language and knowledge of the subject matter.

As presented in the work of Brewer (2000), interview results may also be affected by some degree of forgetting, although weak relationships are more likely to be forgotten than strong relationships.

The quantitative examination of social networks presented is primarily based on the handbook by Scott (1991), in addition to resources provided with the UCINET analysis software (Borgatti, Everett et al. 2002). While preliminary measures of social networks are presented, further analysis may yield more insights into the characteristics of the project team. Additionally, detailed statistical analysis, in addition to elementary measures, would likely allow for the comparison of the data obtained to that presented for other social networks.

Due to the fact that this case study has been primarily exploratory, the conclusions presented do not appear to be easily generalized. Further systematic study would be necessary for ascertaining the utility of the conclusions in other circumstances.

6.4 Directions for Future Work

To some extent, this work suggests possible examination of large project execution on a continuous basis may be useful so as to identify specific tasks and behaviours as they occur, and if possible to examine the effect that these behaviours have on the project. While obtaining the commitment of key team members to participate actively in such an analysis may not be possible, even a limited examination may prove insightful in general, and hopefully to the team member in question.

The incorporation of automatic quantitative analysis methods, as discussed in McGreevy (1995), could be useful in the analysis of larger volumes of verbal or textual data, possibly identifying patterns overlooked in manual analysis. Automated methods may also allow for significantly larger volumes of information.

Quantification of the impact of helpful and unhelpful team interactions could help both project team members and project management to improve day-to-day project execution, resulting in better overall performance. The development of a longitudinal study examining the impact of team member interactions could serve to quantify the costs and benefits of such interactions, as well as illuminate broad and specific categories of both helpful and unhelpful behaviours.

Detailed mathematical analysis of the social network examined in this study may also serve to develop useful insights into the interactions between team members and transfer of knowledge. The interview results provide a rich source of team member interaction information; broad categorization provides only the first steps into the value of the data obtained. From a social network perspective, each category identified may be examined as its own social network, providing additional dimensions of connectivity.

Additionally, framing further work in the principles of business management while at the same time adding further quantitative measures could serve to better integrate this line of exploration into management practice.

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Appendix A

Interview Questionnaire

Identify other team members and technologies it was necessary to interact with in order to complete this project.

Identify ways in which each of the other team members and technologies helped you to get your part of the project done.

Identify ways each of the other team members and technologies did not help you to get your part of the project done.

Identify ways that you helped your team members to complete this project.

Identify ways that you were not helpful to your team members.

What was your role in completing this project?

In what ways were you successful in fulfilling your role in completing this project?

In what ways were you unsuccessful in fulfilling your role in this project?

How could you improve your performance in the completion of this project?

Was this project a successful project? In what ways was it successful or not?

What were the key factors that influenced how successful this project was?

Is there anything that worked really well that you would do again in future projects?

Appendix B

Partial Raw Interview Results

For representative purposes, a subset of interview comments is presented below. Specifically chosen are the helpful and unhelpful comments that have been categorized as knowledge related. Duplicate comments have been removed.

Additionally, comments related to the success of the project, as well as comments indicating the key factors in the success of the project have been presented.

Table 6 - Helpful Knowledge Related Comments

application knowledge - knows the code, knows what was already there
blast furnace field device knowledge
came up (to contractor site) ahead of time to pick his brain
chemistry perspective
confident blast furnace control system knowledge source
customer knowledge
data support (lists of materials, other information technology support)
experienced with it
expert knowledge for operational requirements (technical requirements)
Extensive knowledge
filled in for CTL when CTL was unavailable for blast furnace technical knowledge
gave tour of Stockhouse - good overview of mechanics of system
GE hardware knowledge for relocation of temporary PLCs (existing Stockhouse PLCs)
GE PLC knowledge
GE PLC tutorial
general PLC help - how Modicon and GE PLC work, troubleshooting, technical knowledge
general process knowledge - expert knowledge
General Stockhouse as-is knowledge and support
good knowledge of existing control system design
good learning resource
he was “technical guru”
helped with J7 questions

HMI and process knowledge
how it affects their day-to-day operation, functionality
if reason why in old program wasn’t clear - he would say why and indicate how end result justified the means
installation knowledge
internal SAF drive expert
knack of understanding automatic / feedback control systems, more experience
knew existing operation well
knew how the furnace had to operate
knowledge of blast furnace operation - guy to sound off of
knowledge of existing problems
knowledge of how it worked and what they did to make it work
knowledge of technical idiosyncrasies
knowledge of what will or won’t “Fly" with maintenance
knows system very well
knows where the furnace is, where ASI would like it to be, and know / decide if it is possible
main resource on the old system - why the program was done the way it was done
Modicon hardware knowledge and access to technical support
most knowledgeable person at ASI for GE Series Six hardware
PICS knowledge
process knowledge
production perspective
same as CPS, but more of a tuning / efficiency perspective
technical guru on how it works
technical support on as-is operation (technical resource)
Thoroughness with initial investigation - ensured “valid, updated” information
understanding of the project
understood the impact on the operation
understood the process
very good memory
Very good reference

very well versed with blast furnace function and how it should work and its problems
well known - in plant since 1970’s

Table 7 - Unhelpful Knowledge Related Comments

at start, no Concept knowledge, limited Modicon hardware knowledge
Didn’t have good process knowledge at start of project
documentation too general
Ethernet - a bit confusing
expected team members to know things they didn't know
hindered by lack of knowledge
lacked knowledge (at start) of how the blast furnace charging system functioned
lacked knowledge on GE System
may not be keeping up with system expansions
no knowledge of the GE PLC
not enough documentation
not experienced
process knowledge - hindered since starting from greater initial knowledge lead to poor communication
questions he asked tended to indicate that he lacked understanding of the process
sometimes forgetting things - errors

Table 8 - Comments Regarding Project Success

achieved project goals (upgraded control system and new functionality)
company made money
customer believes in our competence, wants to do more business with us
customer happy
delivered within a reasonable schedule
did it safely (personal safety)
didn't break anything
expected project savings surpassed

got it done with minimal (next to none) interruption to process - did it while it was running
it works, does what it was supposed to do
maintained tight schedule without wrecking anything
met its objectives
minimal interruption to operations to changeover - big plus!!
no lost production
no major problems when it went into service
on budget
outdated hardware has been replaced
people happy - all developed and learned
profitable
shareholders happy
short commissioning time
very (unreasonably) short timeline - got it done and working

Table 9 - Comments Regarding Ways Project Was Not Successful

Intermittent issues which were hard to troubleshoot internally due to application knowledge limitation of internal resources which was the result of not having ability to be focused on this project throughout development
people unhappy – VTL2 left the company
some problems appeared well after commissioning

Table 10 - Key Success Factors Identified

communication
competent team members
concrete requirements in operation of a machine
cooperative and involved customer
dedicated team members
dedication of team members to success of project and long term operation of blast furnace
desire of whole team to succeed

everybody got along well personally
everybody worked very hard, especially since time was tight
good organization (CPM and VPM)
image of project was positive
in the end, the idea of charging nut coke worked - furnace was capable
nobody took positions they wouldn't back down from
project management (VPM)
quality team members from both ASI and Brock
some team members only filled small gaps or contributed for short durations but these contributions were very important to overall success
team all pulling in the same direction
team members used individual skills to support each other and the project success
technology used
very knowledgeable people
very skilled team
CPM and CTR2 had very good knowledge of how the system worked
working in an ego-less environment

Only a single factor was identified as contributing to a lack of success in the project – “lack of communication / poor quality communication”.

Appendix C

Aggregated Interview Results

Table 11 – Comment Percentages by Interviewee

Interviewee	Comments	Helpful (%)	Unhelpful (%)
VPM	83	55	45
VTL1	68	69	31
VSD	51	53	47
VTR1	69	72	28
CPM	121	80	20
CTL	136	72	28
CMS	56	77	23

Table 12 – Comment Percentages by Category

Category	Number of Comments	Helpful (%)	Unhelpful (%)
Job Task	129	87	13
Characteristics	84	73	27
Knowledge	78	79	21
Capabilities	51	67	33
Behavior	46	54	46
Management	45	69	31
Performance	44	59	41
Communication	34	82	18
Job Role	22	86	14
Failure	20	0	100
Availability	17	0	100
Declaration	11	82	18
Social	3	33	67

Table 13 - Comment Percentages by Subject

Subject ID	Comments	Helpful (%)	Unhelpful (%)
1	52	90	10
2	48	73	27
3	42	81	19
4	19	68	32
5	44	52	48
6	6	50	50
7	21	90	10
8	38	63	37
9	38	63	37
10	19	74	26
11	19	63	37
12	47	49	51
13	17	53	47
14	18	67	33
15	6	67	33
16	6	33	67
17	12	50	50
18	16	25	75
19	21	86	14
20	8	100	0
21	14	71	29
22	2	100	0
23	5	100	0
24	10	90	10
25	4	75	25
26	7	57	43
27	4	100	0
28	3	100	0
29	2	100	0

Subject ID	Comments	Helpful (%)	Unhelpful (%)
30	1	100	0
31	6	67	33
32	2	50	50
33	1	0	100
34	8	75	25
35	5	100	0
36	5	40	60
37	3	100	0
38	5	40	60

Table 14 - Helpful Comment Summary

		Comments Made By						
		CPM	VSD	CTL	VTR1	VTL1	CMS	VPM
Comments Made About	CPM	5	2	6	1	1	4	5
	VSD	4	3	2	0	3	0	4
	CTL	4	1	8	5	2	2	2
	VTR1	5	2	4	2	3	0	3
	VTL1	7	2	10	7	4	2	2
	CMS	2	1	3	0	3	2	3
	VPM	14	4	2	4	6	2	3
	CDBR	0	0	0	0	0	2	0
	CCNST	0	0	6	0	0	2	0
	CDES	5	0	8	0	0	5	0
	VCO	1	0	0	1	0	0	0
	CAS	0	0	2	0	0	0	0
	VIT	0	1	0	0	0	0	0
	VTR2	16	2	8	11	5	1	4
	CEMT	0	1	0	0	0	0	0
	CAM	7	0	5	0	0	0	0
	VTST	0	2	0	0	0	0	1
	CPS	0	0	0	0	0	4	0
	CMTD	5	0	0	0	0	0	0
	COP	4	0	5	0	0	0	3
	CMS	0	0	0	0	0	3	0
	CTS	0	0	2	0	0	3	0
	SEQ	0	0	0	0	0	1	0
	CAR	3	2	2	0	0	3	0
	VTL2	4	1	3	5	4	3	3

Table 15 - Unhelpful Comment Summary

		Comments Made By						
		CPM	VSD	CTL	VTR1	VTL1	CMS	VPM
Comments Made About	CPM	3	1	6	1	0	1	2
	VSD	0	2	0	0	0	0	1
	CTL	2	1	3	3	1	2	2
	VTR1	0	0	0	0	0	0	2
	VTL1	0	2	0	1	2	1	2
	CMS	2	0	1	0	0	1	1
	VPM	0	1	2	2	4	3	1
	CDBR	0	0	0	0	0	0	0
	CCNST	0	0	0	0	0	0	0
	CDES	0	0	0	0	0	1	0
	VCO	0	0	0	3	0	0	0
	CAS	0	0	0	0	0	0	0
	VIT	0	1	0	0	0	0	0
	VTR2	0	1	0	0	2	0	2
	CEMT	0	1	0	0	0	0	0
	CAM	2	0	2	0	0	0	0
	VTST	0	0	0	0	0	0	3
	CPS	0	0	0	0	0	0	0
	CMTD	0	0	0	0	0	0	0
	COP	3	0	2	0	0	0	2
	CMS	0	0	0	0	0	0	0
	CTS	0	0	0	0	0	0	0
	SEQ	0	0	0	0	0	0	0
	CAR	1	1	1	0	0	1	0
	VTL2	4	2	6	1	3	1	4

Table 16 - Aggregated Net Helpfulness Results

		Comments Made By						
		CPM	VSD	CTL	VTR1	VTL1	CMS	VPM
Comments Made About	CPM	2	1	0	0	1	3	3
	VSD	4	1	2	0	3	0	3
	CTL	2	0	5	2	1	0	0
	VTR1	5	2	4	2	3	0	1
	VTL1	7	0	10	6	2	1	0
	CMS	0	1	2	0	3	1	2
	VPM	14	3	0	2	2	-1	2
	CDBR	0	0	0	0	0	2	0
	CCNST	0	0	6	0	0	2	0
	CDES	5	0	8	0	0	4	0
	VCO	1	0	0	-2	0	0	0
	CAS	0	0	2	0	0	0	0
	VIT	0	0	0	0	0	0	0
	VTR2	16	1	8	11	3	1	2
	CEMT	0	0	0	0	0	0	0
	CAM	5	0	3	0	0	0	0
	VTST	0	2	0	0	0	0	-2
	CPS	0	0	0	0	0	4	0
	CMTD	5	0	0	0	0	0	0
	COP	1	0	3	0	0	0	1
	CMS	0	0	0	0	0	3	0
	CTS	0	0	2	0	0	3	0
	SEQ	0	0	0	0	0	1	0
	CAR	2	1	1	0	0	2	0
	VTL2	0	-1	-3	4	1	2	-1