Boundary Analysis of New Technology Insertion

by

Randy J. Mocadlo

Submitted to the System Design and Management Program
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Abstract

Hamilton Sundstrand has considered their ability to incorporate new technology to establish a competitive advantage a core competency. New technology is not readily accepted in the aerospace industry and requires careful planning and diligence before it will receive certification for use on customer product. To provide a competitive advantage the adoption of the new technology must be rigorously planned, thoroughly tested and precisely applied.

To implement the new technology of commercial plastic components Hamilton Sundstrand created an implementation team. This team researched the new technology to understand the impact it would have on existing processes, skills and technical experience. This evaluation, known as boundary analysis, looks at the way knowledge is created and transferred among individuals or groups. The implementation team generated many changes to the existing systems. New processes were created while some existing ones were just modified to be able to incorporate the new technology. Early results indicated a very successful implementation of the new technology. Over time though the processes designed to transfer knowledge between individuals and groups became more problematic and resulted in the degradation of some of the early successes experienced.

This research will take a look at the new boundaries that were created and the tools and processes developed to promote the transfer of knowledge across those boundaries. The analysis will look at boundaries, processes and tools created during the implementation of the new technology. The analysis will look at the effectiveness of the new processes and tools that were created as well as the consequences that technological advancement and organizational change had on the processes and tools over time.

This research will conclude with a discussion of the research results and a summary of the underlying themes that resulted in the degradation of knowledge transfer across boundaries.

Thesis Supervisor: Paul R. Carlile
Title: Assistant Professor of Management at the Sloan School of Management

Biography

The author, Randy Mocadlo, has been employed at Hamilton Sundstrand for over 16 years. During this time he has held positions of increasing responsibility in the operations and engineering organizations. Previous to his acceptance in the Systems Design and Management Program at the Massachusetts Institute of Technology, he was the Failure Analysis Engineering Manager within the Central Engineering organization. Prior to this position he was the Manufacturing Engineering manager in the Electronics Jet Engine controls department of the Operations organization.

Mr. Mocadlo received a Bachelors of Science degree in Electrical Engineering from Worcester Polytechnic Institute in May of 1985, a Masters of Science degree from Rensselear Polytechnic Institute in May of 1993 and will receive a Masters of Science degree in Engineering and Business Management from the Massachusetts Institute of Technology in June of 2001.

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I want to thank my sponsoring company, Hamilton Sundstrand, for their progressive support and encouragement to advance my educational career. United Technologies educational program has provided me with the opportunity to achieve one of my desired goals of receiving a graduate degree from the Massachusetts Institute of Technology. Special thanks to Briant Hoganson for his support and understanding of the requirements and benefits of the Systems Design and Management program.

I want to thank my thesis advisor, Paul Carlile, Assistant Professor of Management, at the MIT Sloan School. Paul embodies the meaning of educator. Through our meetings and discussions he showed great patience and guidance by leading me to develop my own solutions and not just to reflect his answers. His insight and wisdom has been critical and the opportunity to share an interest with him in organizational processes and boundary analysis will remain one of my fondest memories of the SDM graduate program.

I want to thank the many friends from the SDM class of 2000 that I have had the pleasure to share the past two years with. Special thanks to Jon Niemeyer and Jay Mullooly for insuring the education from MIT was both enlightening and enjoyable.

Finally, a special thanks to my family, wife Michele, sons Ryan and Dustin and daughter Jessica. Their support through the long nights, short weekends and endless time away from home was invaluable. Through their strength I was able to accomplish many things I thought impossible on my own.

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Acronyms

3-T	Reference to knowledge transfer types: Transfer, Translate and Transform
AME	Advanced Manufacturing Engineering
BGA	Ball Grid Array
Brokers	Brokerage houses that sold IC components
CE	Component Engineering
Clockspeed	Reference to the rate of industry technology developement
COQ	Cost of Quality
DPM	Defects per Million
F/A	Failure Analysis
IC	Integrated Circuit
IPD	Integrated Product Development
LDC	lot Date Code
ME	Manufacturing Engineering
MPD	manufacturing Process Development
PCN	Production Change Notification
SPC	Statistical Process Control
TCE	Thermal Coefficient of Expansion
TODD	Top of Die Delamination
UTC	United Technologies Center
UTRC	United Technologies Research Center
WWCS	World Wide Customer Support
WWECQC	World Wide Electronic Component Quality Council

Chapter 1.0 Introduction

1.1 Statement of Problem

New Technology is slow to be adopted in the aerospace industry due to reliability concerns. Historically aerospace companies take a 'wait and see' attitude with new technology not developed internally. This provides the necessary time for the technology to increase reliability and become 'proven'[1]. During the late eighties and early nineties this attitude began to change. Hamilton Sundstrand was experiencing a shift in business away from military to commercial programs. This shift in customers coupled with increasing focus on Wall Street demands brought business pressures to reduce costs and increase growth. The cost pressures caused Hamilton Sundstrand to become more aggressive in evaluating new technologies which could help them reduce cost and become more competitive when bidding for new contracts.

During the mid 1990s Hamilton Sundstrand began to evaluate the use of commercial grade plastic integrated circuit components (referred to in this report as plastic components). Although plastic components had been used in commercial, non-aerospace applications for several years, they were still relatively new to the aerospace environment. Material and technology developments were still occurring at a rapid pace. Hamilton Sundstrand established a new technology insertion team to evaluate the potential use of plastic components. The team evaluated and eventually adopted the use of plastic components. The initial pilot programs implementing plastic components were very successful in achieving their goals for cost reductions and purchasing lead-time reductions without adversely impacting other quality, cycle time or cost metrics.

[1] A term given to technology that had a proven history of reliability through extensive field operation.

Over the years the business environment at Hamilton has experienced many changes. Workforce reductions, mergers, and increased outsourcing have led to many organization and personnel changes. The commercial plastic component IC market has also seen many changes due to technological advancements and process improvements. During this time Hamilton Sundstrand's initial unqualified success in implementing commercial plastic components has been offset by increases in rework costs, manufacturing cycle time and customer returns. During early 2001 the degradation of quality and cost metrics became sufficiently severe to warrant the attention of senior management.

1.2 Motivation

A 'RED Team'[2] was appointed to review the implementation and use of plastic components and the causes behind the degradation of quality and cost metrics over the last several years. 'RED Teams' are management-sponsored teams that are created for a definitive period of time and given the task of resolving critical, high visibility problems. The 'RED Team' is given wide-ranging authority and has priority in resource allocation. The 'RED Team' operates for several weeks to several months on a problem primarily focusing in on the critical processes involved. New sources of novelty (changes introduced into the system) are examined and a 'gap analysis' is performed to identify inefficiencies in the old process resulting from the novelty introduced. A new process is then developed that will operate efficiently incorporating the new sources of novelty that have been introduced into the system.

The recommendations from the 'RED Team' are incorporated and a new process is released that efficiently operates in the new environment as redefined by the new sources of

[2] A 'RED Team' was a high profile team of experienced engineers assigned to resolve a visible, important problem. The team was temporary and had priority of resources to accomplish their goals.

novelty. The new process operates efficiently for a period of time, and then begins to degrade in a similar fashion to the process it replaced. This degradation continues over a period of months or years until management initiates a new 'RED Team' to address the new issues thus starting the cycle all over again.

1.3 Thesis Goal

This thesis will utilize boundary analysis to examine the interaction of functional groups and analyze the effectiveness of knowledge transformation between them. The analysis will also look at how the transformation of knowledge has changed over time due to organizational and technological change, and the effect it has had on operational performance. The process of boundary analysis provides a framework to analyze Hamilton Sundstrand's ability to transform knowledge and to adapt to new sources of novelty.

The goal of this thesis is to provide a new perspective when performing process analysis. Through the use of boundary analysis the goal is to identify the reasons for the inefficiencies developing as well as determine the reasons why the process was not able to recognize or adapt to the new sources of novelty that created the inefficiencies. The intent is to provide a form of validation to the findings and actions of the 'RED Team' on their analysis of the plastic component process and to also surface weaknesses in their development of a new process. This analysis is intended to provide future 'RED Teams' with a more thorough process analysis by which to create a dynamic process that will operate efficiently today and be able to adapt to new sources of novelty being introduced over time.

1.4 Thesis Structure

This thesis utilized boundary analysis to evaluate the problems encountered in the implementation of the new technology of commercial plastic components. Boundary analysis is a general analysis technique that can be used to evaluate any process that involves the transfer of knowledge. The results generated from the analysis of the process used to implement plastic components are generalized in the hope that insights and observations can be applied to other process analysis opportunities. The following is an outline of the sections within this thesis and the flow/intent desired when reading the paper.

- ***Chapter 1.0*** provides a description of the new technology initiative of commercial plastic components, a statement of problem associated with the initiative and the goal of the thesis in researching and analyzing that problem.
- ***Chapter 2.0*** provides a background of the implementation of commercial plastic components. This is intended to provide the user with an understanding of the history and development of commercial plastic components and the reasons behind Hamilton Sundstrand's adoption of plastic components.
- ***Chapter 3.0*** outlines the research performed and the philosophy behind the selection of the sources of research. Included in this section is a description of the boundary study framework that is used in later sections for the analysis of selected boundaries.
- ***Chapter 4.0*** describes the evolution of the implementation of plastic components and the problems that resulted. Critical boundaries in the implementation of plastic components are identified and analyzed.

- ***Chapter 5.0*** is a discussion of results from the boundary analysis performed in chapter 4.0. The results are generalized to allow the insight they provide to be applied to any process.
- ***Chapter 6.0*** provides the conclusions to the paper and offers recommendations on how to resolve the some of the issues identified in chapters 4.0 and 5.0.

Chapter 2.0 New Technology Initiative Description

2.1 Strategic analysis of Commercial Plastic Component Initiative

In 1991 a competitive strategy team was assembled consisting of senior managers and technical specialist from Hamilton Standard[3] and United Technology Research Center (UTRC). The primary goal of the team was to identify strategic opportunities that Hamilton Standard could pursue to provide them with a competitive advantage. One of the senior managers from UTRC suggested the use of commercial plastic components to provide a cost advantage on products manufactured by Hamilton Standard. The use of commercial plastic components would also help to solve some of the growing concerns about the availability of suppliers and product diversification being offered in military ceramic components. Hamilton Standard had evaluated the use of commercial plastic several years early but had concluded that the quality and reliability was not sufficient for aerospace products. After researching the advancements that had occurred over the last couple of years the team acknowledge that the quality improvements were sufficient to revisit the issue.

Hamilton Standard was purchasing military ceramic components for their larger integrated circuit devices. The availability of military components was decreasing with several large suppliers having already served notice that they would stop manufacturing military ceramic components. At the same time, the cost of military components was increasing at a high rate. The evaluation of commercial plastic components was timed perfectly to help address both issues of cost and availability. From a manufacturing strategy the use of commercial plastic components did not present a major challenge. The technology to manufacture and assemble the

[3] Hamilton Standard would merge with Sundstrand in 1999 to become Hamilton Sundstrand.

components was considered to be basically the same as military components. Modifications would have to be made to the way the parts were handled and the temperatures that they were exposed to but the majority of the processes used could remain almost intact. The functions of design and purchasing would also remain basically the same as the same performance of military components was expected from commercial plastic and the suppliers who offered military components almost always offered the same device in commercial plastic. As mentioned above, the strategic advantages provided by cost reductions and component availability would increase the probability of winning new contracts. The remaining concern was centered on the quality and reliability that would result if the new technology was adopted. As is pointed out in the next section the concerns of quality and reliability were addressed through extensive research and evaluation of commercial plastic products. Plastic was implemented on new products and helped to provide Hamilton Standard with a competitive advantage that would last until the widespread use of plastic components could be found in a majority of aerospace products.

2.2 Background on Commercial Plastic components

Military components were integrated circuit dies (actual functioning electronics) housed in an open cavity ceramic package. Commercial plastic components were typically the same integrated circuit dies housed in an epoxy resin package. The plastic package was more sensitive to temperature and moisture so it required more controlled handling and manufacturing. Package sizes and lead frames (provide interconnection to circuit board) were the same. See Figure 2.2-1 Plastic Component construction below that shows the construction of commercial plastic components. From an electrical design perspective the functioning die in military and commercial components was the same and offered no change in design requirements. Vibration requirements were also no different. Thermally the commercial plastic was not as conductive and therefore did not dissipate heat as well. The suppliers of the epoxy resins were addressing this and several improvements had already improved the thermal properties over previous resin compounds.

Ceramic devices have numerous construction steps and inspections, and are rarely manufactured at rates exceeding a few hundred an hour. Ceramic was an open cavity package that relied on the seal of the lid to protect the device. Plastic components utilized a molding process for production and employed continuous flow manufacturing capable of production at a rate exceeding 20,000 components per hour on a single line. Commercial plastic used a molded resin for the package that required no cavity and allowed a smaller, lighter package. See Figure 2.2-1 Plastic Component construction for a detailed cross-section of a molded plastic component.

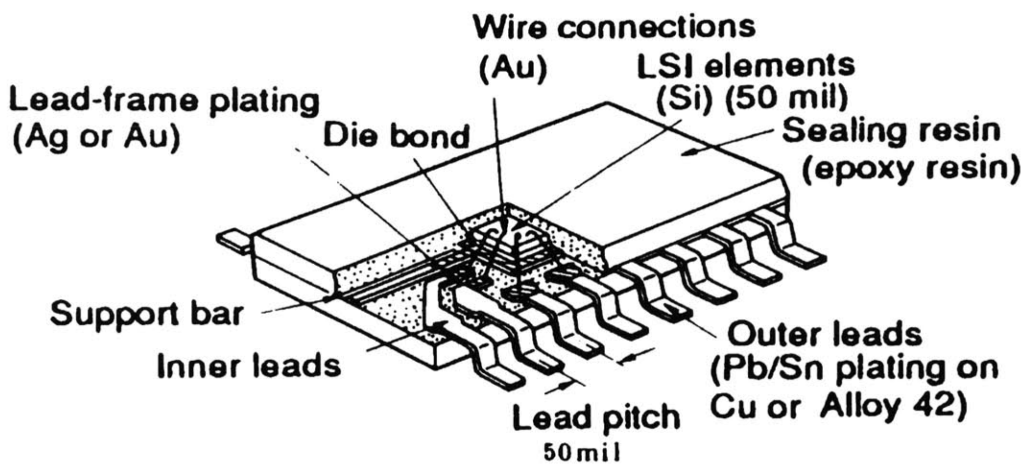

Figure 2.2-1 Plastic Component construction

The failure modes between military ceramic and commercial plastic were different with military more susceptible to poor sealing and particulate in the cavity. Plastic components suffered from top of die delamination and were more sensitive to moisture and temperature. Also, due to the high rate of manufacture with plastic components, when problems did occur they had the potential to result in large batches of defects that may not be detected due to the reduced level of inspections.

Over 90% of the microcircuits manufactured worldwide are plastic encapsulated. Ceramic devices represent less than 1% of the worldwide market. The difference in cost is significant as well with plastic components costing from 1/16th to ½ the price of ceramic components. Plastic components early history was associated with low quality and low/suspect reliability (environmentally inhibited). This life limited their use to equipment with 5-10 year life spans. This reputation marked only the beginning of commercial plastic components and over the years, as the market grew, technological advancements within the industry improved the reliability and quality of commercial plastic to rival and eventually surpass military ceramic. See Figure 2.2-2 Reliability comparison of Hermetic (military ceramic) and plastic components for a chart showing the reliability improvements of plastic components compared to military ceramics. One of the main reasons for the improvement in the performance of commercial plastics was the use of statistical process control. At a manufacturing rate of 20,000 per hour individual component screening was replaced with SPC. Intense SPC controls were used to reduce scrap and variability. SPC eventually was incorporated into all phases of commercial plastic component design and manufacturing. Technological advancements were also critical in improving the materials that were used in the construction of plastic components. Several technological advancements are listed below that improved the performance of plastic components:

- Silica as filler, provides better TCE matching of die/leadframe and epoxy.
- Development of low-pressure epoxies which places less stress on the bondwires during the molding process.

- Reduction of impurities in the epoxies
- Higher glass transition temperatures to increase the temperatures that the component can withstand without degrading or damaging the package.

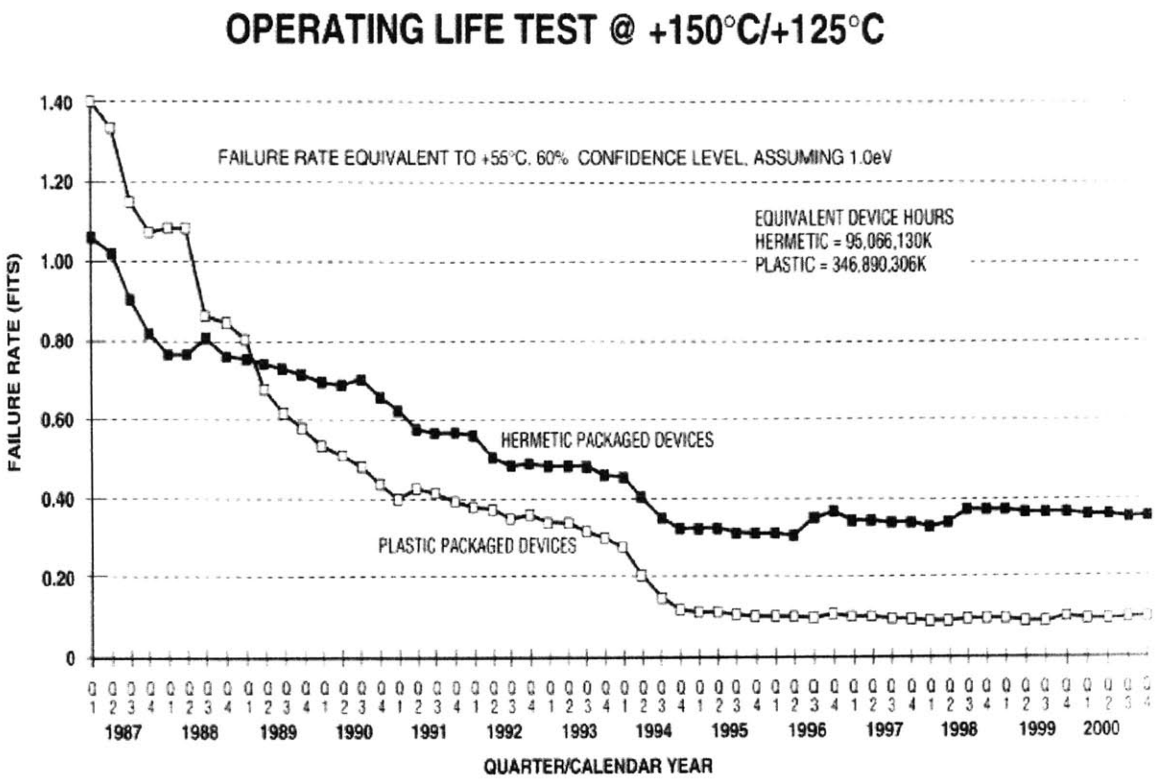

Figure 2.2-2 Reliability comparison of Hermetic (military ceramic) and plastic components

Commercial plastic is a high sales industry. Customers continue to request improvements in the performance, reliability and cost of the devices. This has marked an environment where technological advancements are occurring at a rapid pace. Changes are occurring at a rate measured in months not in years. The changes are not destructive though and each new technology is more likely to improve or build on a previous one rather than replace it. It is because of this that commercial plastic component industry is expected to show continued improvement and change over the next years in the area of cost, reliability, performance and product breadth.

2.3 Program implementation of Commercial Plastic Components

Hamilton Standard initiated an effort to determine the feasibility of using plastic encapsulated microcircuits in their electronic applications in 1991. At the time there was minimal aerospace application utilizing plastic encapsulated components. Coincidentally this effort was initiated when the availability of military components was at its all time Highest. Nonetheless monitoring of industry trends, the increasing costs of military qualified ceramic hermetic devices and the demand for less expensive designs provoked this effort. This initial effort included: Benchmarking with other UTC divisions, conducting thorough reviews of supplier furnished data in regards to reliability testing and reliability development management programs and an exhaustive literature search for independent studies on this subject. The results of this preliminary effort clearly indicated that commercial plastic component technology had potential for successful implementation for Hamilton Sundstrand products. A formal team was put together to coordinate the implementation on a program that was chosen to minimize risk. Hamilton Sundstrand selected the Data Management unit used on the Airbus A321. This program was not flight critical and was housed in a controlled environment. The mix of the electronics circuit board consisted of military ceramic and commercial plastic. The use of commercial plastic was limited to only those components that the team felt confident had a proven reliability record. Also, the combined used allowed comparison of the performance of military ceramic to commercial plastic under the same operating conditions.

At first the team was very hesitant about the use of commercial plastic. Part of the problem originated from the fact that the suggestion to evaluate the use of commercial plastic did not originate from Hamilton Standard. Thus the 'Not invented here' syndrome clouded the issue and enthusiasm at the start of the initiative. The first priority of the team was training. The team needed to develop sufficient experience (requisite variety) with commercial plastic to understand the impact and changes that would result from implementation on Hamilton Sundstrand products. Several team members were sent off to formal training being given by industry experts on the design and manufacturing with commercial plastic components. The majority of the people who received the training were from the components engineering group. The components engineering group was selected because of their extensive knowledge of component technology and the requirements internal to Hamilton Sundstrand placed on new or existing component technology. The individuals who were trained would then train the implementation team. The implementation team was an integrated product development team that had representation from each functional group. This team, once trained, was then responsible for developing a training program that was provided to each functional group.

In addition to the extensive data search and coordination with other UTC divisions that were already using commercial plastic components, actual device qualification testing was done in Hamilton Standard's Components Engineering Lab to determine capabilities of the devices. This too resulted in determining positive capabilities commensurate with existing product requirements. Device testing evolved to board level testing and prove-outs – with successful results as well. With the research and actual testing complete and yielding positive results the decision was made to go forward with implementation on the first product. Through information developed from research, testing, and sharing of reliability data with other UTC divisions a 'best supplier list' was comprised from which the first commercial plastic components would be selected. In 1993 Hamilton Standard fielded it first production units using Plastic parts. This was the Data Management computer used on the Airbus A321. The performance and reliability of the Data Management computer was carefully monitored and eventually proved to be extremely reliable. The implementation was considered to be very successful. The design migration to plastic parts eventually encompassed all of Hamilton Sundstrand's electronic products.

The original team that coordinated the implementation of commercial plastic components on the Data Management computer was kept almost completely in tact and given the responsibility to coordinate the use of commercial plastic on a second program. This program too was very successful. With each success the responsibility, coordination and focus of the implementation would diminish. Commercial plastic had become an accepted and proven new technology. New procedures were put in place that controlled the design, manufacture and testing of commercial plastic components. Unfortunately, the implementation team did not capture the lessons learned, the decision process, the anticipated pace of technology, the detailed technological relationships of commercial plastic to our manufacturing processes or the differences that commercial processes would create compared to our existing understanding of processes design to handle military components.

2.4 Organizational Changes within Hamilton Sundstrand

Since the implementation of commercial plastic components began in the early 1990's Hamilton Sundstrand has experienced a high level organizational change as well as the technological change that accompanied commercial plastic encapsulated devices. The 80's and

90's represented significant shifts away from military products to commercial products. This placed greater demands to control manpower due to government programs being funded, which paid a profit on top of expenditures, compared to commercial which internally funded most of the design and development of a program. In 1996/97 Hamilton Standard acquired Dynamic Controls and in 1999 Hamilton Standard merged with Sundstrand to officially become Hamilton Sundstrand. Both of these business transactions resulted in the introduction of new cultures and strategies that would require extensive coordination if a single company focus was to emerge. Workforce reductions accompanied each merger and acquisition as well as additional layoffs resulting in 2001 due to anticipated low sales growth predicted for 2002/3. The layoffs as well as general business conditions have resulted in high workforce turnover. Some critical central groups, such as components engineering and failure analysis have seen turnover rates as high as 25% plus per year over the period from 1998 to 2001. This has resulted in the loss of experienced, senior engineering's and the tacit knowledge that they possessed. Finally, organizationally reporting structures have changed dramatically. Cross-matrixed reporting structures, merger with geographically dispersed departments due to the merger with Sundstrand, de-centralized reporting structures have been experienced over the last several years making consistency of functional goals and strategies difficult to establish. As an example the components engineering group has seen a change in their reporting structure from engineering to operations to central engineering in the span of less than 4 years. Each reporting structure carries with it slightly different perspectives and goals. The quality department as well has seen a change in their structure from reporting to the quality organization to being split and de-centralized with half of the organization reporting to the operations department and the remainder of the group maintaining their link to the quality organization. These changes represent new relationships, boundaries and priorities and represent delays and inefficiencies as these new changes are adjusted to.

Chapter 3.0 Research Objectives and Methodology

3.1 Objectives

The main objective of the research performed was to understand the boundaries that were created by the initiative to implement the new technology of commercial plastic components. This research was developed to identify the structure of the boundaries and the efficiency of transferring and transforming knowledge across these boundaries. The complexity of the new boundaries is detailed as well as the similarity of the new boundaries and processes, created by the implementation of commercial plastic components, to the old process that involved the use of military ceramic components. Finally, the research focused on the amount and sources of novelty that were introduced into these boundaries and the effect it had on the efficiency of the boundary over time.

3.2 Data Gathering

Data was collected from several sources in an attempt to cover as many perspectives on the complexity and efficiency of the boundaries identified for analysis. The methods utilized to collect data included the following:

Interviews- interviews were conducted with the employees that managed the boundaries or whose job descriptions required them to work across the boundaries. The focus of the interviews was to gain an understanding of the boundaries from the people who worked across them on a regular basis. The questions were design to elicit information on the following boundary characteristics:

- Identify boundary and complexity of the boundary
- Identify tools, barriers

- Identify efficiency and process to transfer knowledge.
- Understand how knowledge is valued and utilized.
- Understand dynamic nature of boundary (sources of novelty introduced and changes/improvements instituted over time)

A total of 11 interviews were conducted lasting an average of two hours each. Where required, follow-up interviews were performed to gather additional information and to ask more detailed questions. This was done on 5 of the 11 interviews. See Appendix B: Interview Questionnaire for a list of the typical questions asked during interviews.

Surveys- Surveys were used to gather information on several focused topics. The survey was utilized to cover a broader base of boundary users. The following is a list of the data topics that were targeted by the questions posed:

- Amount of knowledge captured, problems with knowledge transfer
- Identification of boundaries, method of validation
- Databases used to capture knowledge
- Learning sources
- Barriers

See Appendix A: Survey Questionnaire for a copy of the questionnaire used for the survey.

Reviews of Databases- databases were reviewed to determine the number of databases being used, ownership and the intent of the knowledge being captured. The following information was reviewed to during the database research:

- Ownership, users
- Availability, ease of access, linkage to other databases

- Syntax/semantics of knowledge stored

The following specific databases were reviewed for the following characteristics:

- Failure Analysis database: Syntax and semantic problems (initiator input and reports), ease of access, knowledge capture
- Quality database: captured knowledge, metrics, validation
- Functional group work instructions/procedures: Capture of knowledge, iteration, and validation. Revision history was reviewed to determine number of process revisions and duration between updates.

Observations- where applicable research data was supplemented from insights and experience gained through observations of the activities at the boundaries identified. The following were some of the activities observed during the research done over the first half of 2001:

- Component failure analysis
- 'RED Team' meetings
- Quality investigation meetings
- Supplier coordination meetings
- Functional group meetings

3.3 Boundary Selection

The selection of the boundaries analyzed was done to provide the maximum coverage of the processes involved in the implementation and use of commercial plastic components. Numerous boundaries could have been selected by the number was limited to three to permit sufficient detailed analysis of the boundary. The three selected were considered to be the most important and indicative of the generic problems associated with the transfer of knowledge. The following boundaries were selected:

- New technology- this was the boundary created by the initiative to implement the new technology of commercial plastic components. After the implementation of plastic parts the boundary focus shifted away from implementation of plastic components to normal manufacturing use of plastic components. Once plastic components became a normal manufacturing part of manufacturing the priority shifted away from implementing plastic components to monitoring their use and quality.
- Failure analysis- this was the boundary created by the process of investigating and analyzing the root cause of failures involving plastic components. This process provided information to the quality organization to initiate action to resolve process, component and supplier issues that involve plastic components.
- Quality Control- the boundary created by the process of quality control was responsible for reactively working plastic component problems that surfaced as part of the purchasing, use and testing of plastic components. This process relied on the failure analysis process for much of the technical knowledge required to understand and resolve the problems being experienced.

3.4 Data Source Selection

The sources selected for research were chosen to provide a wide range of perspectives. Interviews were selected with the goal of selecting individuals at varying levels of responsibility and with a minimum number of years experience involved in the processes and boundaries selected. Where boundaries were identified the research sources were designed to get perspective from multiple boundaries users from as many of the different functional groups that worked across the boundary. See Figure 6.7-1 Interview statistics: Pareto by Job Description and Figure 6.7-2 Interview statistics: Pareto by yrs of Experience for information on the work experience and job position of the interview participants. Database review and observations were selected to supplement the information developed during the interviews and analysis of the survey responses.

3.5 Boundary Study Framework

The intent of a framework with which to analyze boundary activities is to create a procedure that will provide a consistent, repeatable process. This is meant to be stable but not rigid. The framework is designed to allow improvement and efficiency through the iteration of a common process thereby promoting the incorporation of lessons learned and new knowledge generated.

Hamilton Sundstrand did not employ a consistent framework when confronted with the task of implementing a new procedure or reviewing an existing one that was functioning poorly. The procedures Hamilton used to implement a new process or review an existing one were ad hoc and mainly dependent on the skill of the individuals tasked with the responsibility. The procedure was rarely documented, never repeated and didn't exist long enough to formally incorporate lessons learned or new knowledge.

In addition to the problem of not having a standard process on which to build and improve the following are additional concerns that would benefit from the development and use of a standard process:

- Hamilton Sundstrand addressed the technical 'engineering issues' when they evaluated a new or existing process. They developed complex, technical processes that were initially effective but broke down long-term because they were not flexible and didn't address the organizational and boundary issues of transferring knowledge across functional departments.
- The existing process was rigid and did not know how to deal with the introduction of new novel sources of input.
- The existing process looked at how the functional groups were dependent upon each other but did not look at the interactions between the functional groups to support these dependencies.
- The existing process looked at the exchange of information but not the transfer of knowledge. Knowledge representing the exchange of data and information that can be transformed into value.
- The existing process was designed to deal with the present state of conditions and didn't attempt to anticipate the affect or impact of future states.

The following section will put forth a framework that will provide a consistent process and addresses the concerns previously raised. This framework is not intended to be a complete process development methodology but rather one of several parts elements to create such a process. Further detail will be given to the idea of a process development methodology in chapter six.

3.6 Boundary Analysis

One of the primary goals of boundary analysis is to reduce the amount of variability that exists at a boundary to enhance the effectiveness of knowledge transfer. Variability at the boundary creates inefficiencies in the formation, transfer and translation of knowledge across the boundary from one user to another. Boundary analysis attempts to identify where the variability will come from, what the impact will be and then steps to minimize the impact of that variability. The following section on boundary analysis will look at understanding and identifying the complexity at the boundary and then utilize the '3-T' framework[4] to classify the type of boundary, identify barriers and recommend tools to deal with the boundary. Before we begin to develop the framework it will help to define several terms that will be referenced throughout the paper. The term and definitions are provided below:

- ***Boundary*** (knowledge boundary) is a reference to the functional gap that exists between two or more individuals or groups that makes exchanging knowledge between them problematic. The individuals or groups exchanging knowledge will be referred to as 'boundary users' or just 'users' within this paper. The problems in the transfer of knowledge are due to the dependencies, differences and sources of novelty that exist between the users exchanging knowledge. These problems require the boundary to be managed to minimize the negative affect they will have on they exchange of knowledge.
- ***Dependence*** refers to the properties of knowledge that share a common need across the boundary. The property of dependence, or sources of dependence arise because knowledge has shared relations, interfaces or reliance across functions. If there is no dependence then the sharing of knowledge has no value to the individuals or groups involved and there is no boundary.
- ***Difference*** refers to the properties of knowledge that are exclusive to an individual or group and need to be salient when knowledge is shared. The property of difference, or what we

[4] Reference to Paul Carlile's paper A "3-T Framework" of Knowledge Boundaries.

could more descriptively label as sources of difference, arises because knowledge is naturally localized, embedded and invested in different practices[5]. If there is no difference then again there is no boundary created because the knowledge can be shared directly without barriers or problems arising due to differences in the sources of knowledge.

- *Novelty* is defined as new sources of input or change to the boundary that are unique. The sources of novelty represent new dependencies and differences for knowledge being transferred across the boundary.
- *Requisite variety* can be explained as developing a portfolio of different skills and capabilities designed to develop the knowledge and experience necessary to understand the novelty being introduced. By developing requisite variety it allows the users at the boundary to react and adapt quicker to new sources of novelty.
- *Path dependency* is the condition of solving new (novel problems) with old experience that does not resolve the new dependencies and differences created. Referred to as the 'Competency trap', people and procedures have a tendency to handle novelty using knowledge and experience that are familiar to them and that they feel comfortable with using. The competency trap is a reference to using competencies that have already been developed and are useful in dealing with new sources of novelty but not sufficient to create effective new solutions.
- *Barriers and Boundary Effects* inhibit or negatively influence knowledge that is being transferred across a boundary.

[5] Carlile, P. 2001. A "3-T Framework" of Knowledge Boundaries

- *Boundary Objects (tools)* support the transfer of knowledge across a boundary. Examples of boundary tools are repositories, standard work and models. The tools provide a means to represent and share the knowledge between users at a boundary.

3.6.1 Boundary Complexity

The first step in boundary analysis is to identify the boundary. This includes defining the intent of the boundary. What knowledge are we trying to transfer across the boundary and what needs or solutions is this knowledge designed to meet. The boundary owners and users must be clarified. The roles and responsibilities of both the owners and users of the boundary should be identified. Owners will need to understand their role in providing resources to operate and maintain the boundary. Users will need to identify how they will operate at the boundary, what their expectations are and what the expectations are of the other boundary users that they will interact with. After goals, owners and users at the boundary have been identified the next step will be to understand the complexity at the boundary.

The higher the degree of complexity the more problematic the boundary will be in effectively transferring and transforming knowledge. Although there are many influences of boundary complexity we will limit our discussion to the following four:

- Quantity of Information being transferred: the higher the quantity the greater the demands on the capacity and bandwidth of the tools and procedures for storing, transferring, and transforming knowledge.
- Technical content: indicates the level of technical content of the information being transferred. High technical content places added responsibility on boundary users to understand the meaning and context of the knowledge being shared.

- Functional specialization: indicates the level of specialization of the users at the boundary. Specialization represents job functions, usually technical, that have minimal overlap of capabilities or responsibilities with other job functions. This results in knowledge that is highly localized and difficult to transfer.
- Novelty: defined as sources of new differences or dependencies. The greater the novelty introduced the more demand will be placed on the system to adapt and evolve to the novelty. This will require the development of new to negotiate the new sources of novelty. Novelty is characterized by the source, magnitude, impact and timing. Source-Where is the novelty coming from? Magnitude- how significant are the changes that are occurring? Impact- How significant will the modifications be that are driven by the change? Timing- how often are changes being introduced and how quickly must the user respond to the changes? There are two types of novelty, internal [infrastructure] that modifies how you exchange knowledge, and external, that will require new and novel approaches. Internal novelty might include changes resulting from restructuring, mergers, entering a new product market etc. The internal novelty will not change the actual information or data (form or function) but will change who the users are, how the data is exchanged or the intent or use of the data. External changes to the boundary are a result in new sources of novelty that will require new solutions. Technological advancement was the most common example of external novelty experienced.

Complexity at a boundary will place increased pressure on the users to understand and adapt to these complexities. The proper selection of tools, skills and procedures will be critical in promoting the exchange of knowledge and its transformation into new, value added solutions. Requisite variety of knowledge will need to be developed to handle the most problematic issue of new sources of novelty. Requisite variety does infer some level of predictability in anticipating what the new sources of novelty might involve and therefore creating a training program to develop the learning required. Learning is used to denote the development of knowledge after the problem or challenge has been identified. Learning can be characterized as the exchange of knowledge that is likely to result in the satisfaction of a need or solution of a problem[6]. The success of that learning leading to the satisfaction of a need or solution of a problem is very dependent on the boundary complexity and the background and values of the participants that are defining the learning process. People are path dependent, which can be also stated as people tend to do what they know. Learning must first define a search space and then narrow this area to define a solution space. If the people defining the search space limit the area too much because of their background they may not include sufficient space to find the most efficient solution.

3.6.2 "3-T" Framework

Paul Carlile, in his paper 'A "3-T Framework" of Knowledge Boundaries', described three primary knowledge boundaries, syntactic, semantic and pragmatic. The '3-T Framework' was a reference to the types of boundary modes used to deal with the conditions present at each boundary. The three modes are transfer, translate and transformation. A short review of Carlile's framework will be provided in the following section. This framework will be used as a basis for the analysis of the boundaries created through the introduction of the new technology initiative presented later in the paper.

[6] Carlile, P. 2000. Into the Black Box: The Knowledge Transformation Cycle

When describing knowledge transfer three primary boundaries types exist, (1) syntactic, where the boundary mode is characterized by the transfer of knowledge, (2) semantic, where the boundary mode is characterized by the translation of knowledge across the boundary, and (3) pragmatic, where the boundary mode is characterized as a transformation of knowledge across the boundary generating new knowledge or new solutions.

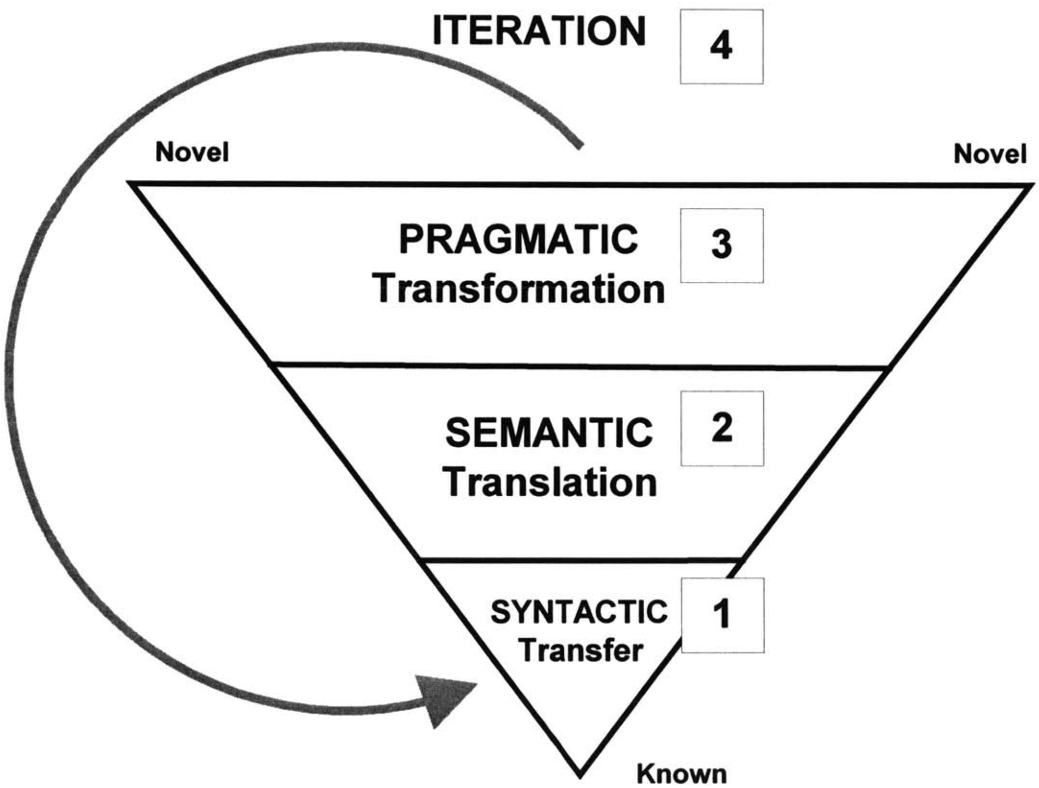

Figure 3.6-1 Characteristics of Boundary Process[7]

Figure 3.6-1 Characteristics of Boundary Process shows the four characteristics of boundary modes. The inverted triangle is a representation of the boundary involved. The point of the inverted triangle represents the state of the boundary where the knowledge and processes are known and stable. No gap exists and exchange of knowledge is not problematic. As you begin to move up the inverted triangle the knowledge and processes involved become more novel and

[7] Carlile, P. 2001. A "3-T Framework" of Knowledge Boundaries.

the boundary gap (represented by the width of the triangle) becomes larger and more problematic. The three boundary types are labeled as 1, 2 and 3 and will be described below. Iteration, which is common to all three boundary types, is labeled as number 4 and will be addressed later in the chapter under the section of dynamic evolution.

The most simplistic boundary type is syntactic. Syntactic establishes some shared language/syntax of representing each other's knowledge[8]. Syntactic is represented on the figure as the tip of the inverted triangle. The level of novelty is minimal and the boundary gap is small. The exchange of knowledge is not very complex nor the differences very problematic. Through the development and use of a shared common language, knowledge is exchanged manually, or automated through the use of repositories (databases and networks). Minimal interaction or interpretation of the knowledge is required before it can be applied. No other boundary type is involved. Through iteration and the use of automated database management tools syntactic boundaries can be very effective and efficient at the transfer of simple, stable forms of knowledge.

Semantic is the next boundary type and must deal with increased novelty resulting in new dependencies and differences and a larger, more problematic boundary gap. Semantic boundary provides individuals a concrete means of specifying their differences and dependencies. The different degrees of uncertainty driven by the novelty in the knowledge will require greater control and understanding (learning) of the dependencies and differences that exist at the boundary. The differences and dependencies will have to be clarified so that the exchange of knowledge will include sufficient awareness of the context and meaning of the knowledge to understand the consequences and impact of that knowledge. This will require boundary tools

[8] Carlile, P. 2001. A "3-T Framework" of Knowledge Boundaries

that are developed by the users that address the syntactic requirements of the boundary (common language) and also tools that develop an understanding of the dependencies and differences of the knowledge. Standard work, simulations and process maps are examples of tools that can be used to identify dependencies and differences in the creation and use of the knowledge. Iteration will increase efficiency through increased level of experience in the users and will also promote the inclusion of new knowledge generated by novelty within the system that has been identified and absorbed.

The most complex and problematic of boundary types is referred to as a pragmatic boundary. The pragmatic boundary is characterized by high degrees of novelty being introduced resulting in a large boundary gap. A pragmatic boundary is built upon and includes both the syntactic and semantic boundary types. A pragmatic boundary facilitates individuals in negotiating and transforming their knowledge in order to create new knowledge[9]. The process of generating new knowledge is designed to fulfill needs or to create solutions that developed as a result of the introduction of new sources of novelty. As an example the introduction of commercial plastic components was novel to Hamilton Sundstrand's manufacturing processes and required the creation of new processes and solutions to successfully incorporate the new technology. Tools developed to facilitate a pragmatic boundary type are designed to provide users with the knowledge and processes to explore and negotiate trade-offs and consequences of decisions (solutions). This provides an opportunity to generate new knowledge (innovation, novelty). Objects and models are examples of tools simulate a product or process and allow the manipulation of inputs to explore different solutions and negotiate consequences with the users involved. Through a series of iterative concessions (trade-offs) a solution is reached. Through

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[9] Carlile, P. 2001. A "3-T Framework" of Knowledge Boundaries

iteration of this process the new knowledge will be absorbed into the system at the syntactic and semantic boundary levels. The iteration of the process, and the creation and absorption of the new knowledge, will result in meeting new needs and the development of new solutions required as a result of the novelty introduced.

With an understanding of the different boundary types it will help to look at barriers that impede the transformation of knowledge across the boundaries. The following are several characteristics of knowledge or boundary objects that act as a barrier to or have a negative effect on the transformation of knowledge:

- Complexity: The increased level of complexity will place greater technical and organizational demands on boundary users to transfer, translate and transform knowledge.
- Uncertainty (novelty): Increased levels of uncertainty will require developing new processes and knowledge to minimize the impact it can produce.
- Processing capacity (Communication patterns): The processing capabilities of the networking and database tools must be sufficient to allow fast, effective and cost efficient transfer of knowledge between users.
- Processing capacity (Sophistication): The processing capabilities of modeling tools must be sufficient to allow the generation, sharing and negotiation of complex models.
- Requisite variety: The higher the level of global knowledge and experience a boundary user possesses will allow the user to absorb data more effectively when sources of novelty are introduced.
- Non-linear and dynamic – As more knowledge is exchanged it may change effects/outcomes of previous decisions. This effect will also result in delays as it may require extensive

knowledge and time to change inclinations developed as a result of earlier knowledge exchanges.

- Honesty (recognition)– Users at the boundary must recognize their limitations and then be honest in communicating what those limitations are. If the users do not recognize the capabilities of each other or are not honest in communicating those capabilities it will result in limiting the amount and value of knowledge being transferred.
- Structural inertia- Movement from core capability to core rigidity. As a capability is captured in the architecture and processes of an organization to increase efficiency it also results in the capability becoming rigid and difficult to adapt to new sources of novelty introduced into the system
- Path dependencies: Probably one of the more problematic characteristics encountered when dealing with novelty. Path dependency is the condition of solving new (novel problems) with old experience that does not resolve the new dependencies and differences created. Path dependency can also be thought of as misrecognition of the requirements of the boundary created by the new sources of novelty.

Boundary barriers and effects inhibit the transfer, translation and transformation of knowledge across boundaries. The next two sections will look at creating a process that will help to identify and resolve these barriers and effects. Dynamic evolution utilizes the process steps of validation to identify inefficiencies, and iteration to promote learning and the creation of new knowledge. Finally, knowledge representation looks at the issues of capturing the knowledge transferred and new knowledge created.

3.7 Dynamic Evolution

Dynamic evolution of the boundary process indicates an ability to adapt to change (novelty) or to create change to promote improvement. Dynamic evolution involves the process steps of validation and iteration and is discussed in further detail in the following sections.

3.7.1 Validation

Validation is the practice of identifying the value in a process, setting goals and then establishing metrics to monitor the status of achieving those goals. In order to effectively measure the process it may require breaking down the process into its critical sub-process elements. Each sub-process, depending on how critical its impact on the overall process, may require monitoring. Validation provides two benefits as part of the boundary process. First, it identifies the value inherent in the transfer, translation and transformation of the knowledge. By reconciling the value of the knowledge with the users at the boundary it promotes honesty and generates improved understanding of the dependencies and differences that form the basis of the value of the knowledge. Second, by monitoring the status of the process it allows the users at the boundary to evaluate progress towards a desired goal as well as testing their understanding of the system. By establishing goals the boundary users are challenging their understanding of the system. By establishing metrics and monitor the status of those metrics against estimated goals, it allows the users to evaluate their understanding of the response of the system, i.e. did the system respond as expected or are there other factors in effect that have not been identified that are causing estimates to be inaccurate. This allows a form of learning to increase the understanding of system dynamics that are in effect causing reactions in response of the system. Also, by monitoring the effectiveness of the system it allows the users to monitor progress towards a desired goal as well as consistency in performance. This aspect of monitoring will help to identify inefficiencies in the system that need to be identified and whose effects need to be eliminated or minimized, i.e. the dependency trap may show up as inefficiencies in the system, which once identified, may lead to the requirement of developing a new process to achieve the desired goals.

3.7.2 Iteration

Iteration is the repetitive operation of a process that results in increased experience and improved process execution. Iteration is also the planned repetitive process of identifying the need to promote change and implementing process improvements. Through the use of an iterative approach the process allows for the identification of novelty, the absorption of new knowledge and the opportunity for formalized process analysis to determine if changes are necessary and whether new solutions are robust and effective.

Through an iterative approach to execution of knowledge transfer it allows consistent execution critical in gaining experience and efficiency. This also allows the user to identify when new sources of novelty have been introduced. As the novelty is introduced it allows validation to identify the impact that the novelty has on the system on therefore the level of response required to minimize the impact from that novelty. As the impact and response to novelty is developed it will generate new knowledge that needs to be absorbed into the process. Iteration of the process provides an opportunity to apply new knowledge (experience, process improvements, learning etc.) to reduce uncertainty and then to validate the effect of the new knowledge by monitoring success (positive effect on metrics). Finally, iteration allows for formalized process improvements through promoting change and evolution. In the early development of a process significant time and energy is put into developing new tools and learning to insure the development of an effective, efficient process. An iterative approach incorporates a sustained level of process improvements designed to promote sustained growth through evolutionary change and adaptation.

3.7.3 Knowledge representation

Knowledge representation specifies how knowledge is stored, retrieved and then transformed to insure that it adds value back into the system. Knowledge can be either tacit or explicit. Explicit knowledge is clearly defined (externalized) and readily available to be shared with others. Tacit knowledge is specific to individuals (internalized) and must be converted to explicit knowledge before it can be transferred or captured.

From \ To	Tacit	Explicit
Tacit	Socialization - On the Job training - Apprenticeship	Externalization
Explicit	Internalization	Combination

Figure 3.7-1 Transformation of Knowledge types

Much of the knowledge that exists at or across a boundary (organizational or individual) is tacit and must be converted to explicit knowledge (externalized) if knowledge is to be properly represented and achieve maximum value when being retrieved and transformed. It is not within the scope of this paper to attempt to define the types of knowledge, or the processes involved converting that knowledge into a format that can be easily transformed. The intent of this paper is to cover the transfer of knowledge across boundaries and not the issue of representing and transforming knowledge explicitly.

Storage of knowledge can be characterized technically and strategically. Technically the issues of capacity, ease of access, speed, cost of maintenance and content are important factors in the storage of knowledge. Content implies storing sufficient data such that when it is retrieved it can be reconstructed to accurately represent the original knowledge. Strategically the storage of data needs to look at what knowledge will provide a source of competitive advantage. Not all knowledge has value and therefore not all knowledge will add value when stored. Knowledge storage will need to determine what has enduring value and therefore will be beneficial to store.

Retrieval of knowledge again can be looked at technically and strategically. Technically how easy is it to find the knowledge desired and to reconstruct it so that it may be transformed later to recognize the intended or desired value. Strategically the retrieval of knowledge must look at how the value of the knowledge has changed over the time from its capture to its retrieval. As novelty is introduced into a system it has the capability of making the knowledge stored obsolete. The retrieval process must be able to understand how the value of the knowledge has changed over time to insure it is not inappropriately applied.

Transformation of knowledge can be viewed primarily from a process standpoint. Once the knowledge has been stored and retrieved how effective is the process in assimilating the knowledge to generate new knowledge or solutions? This is a measure of how re-usable the knowledge is and how effective the process is at interpreting and applying the knowledge to the situation intended.

Chapter 4.0 Boundary Analysis

A boundary analysis of new technology insertion was conducted using the framework developed in chapter three. To accomplish this analysis the boundaries associated with the initiative of inserting a new technology were identified. Because of the numerous requirements and tasks involved, and the limited time available, the initiative of new technology insertion was reduced to analyzing three critical systems: (1) integration of new technology, which was responsible for the identification and implementation of new technologies, (2) component failure analysis, which was responsible for analyzing component failures and determining root cause, and (3) Quality control, which was responsible to insure quality standards were being met and that customer satisfaction with product quality and reliability achieved divisional goals. Each of these major systems represents a high-level conceptual boundary that consists of several smaller functional boundaries. The analysis performed will look at the boundaries across each of the three critical systems. General observations and findings will be made about each system. Where applicable direct examples of specific boundaries analyzed will be made to illustrate general observations rendered. Before the results of the analysis are presented a historical perspective of changes that occurred at Hamilton Sundstrand is outlined to provide additional background. This information will provide context that will be beneficial to understanding some of the analysis and recommendations put forth later in the paper.

4.1 Evolution of Initiative over time:

Chapter 2.4 identified the organizational changes that Hamilton Sundstrand experienced since the initiative to implement commercial plastic components began. Further detail is provided below on functional department changes that occurred as a result of the organizational changes:

- Components engineering was taken out of the Engineering organization and re-assigned to the Operations organization. Engineering's priorities centered on technical issues of design and reliability. Operation's priorities concerned resolving part shortages and obsolescence issues. This reduced the time and priority that Components Engineering was spending on technical issues and capabilities.
- The Quality organization split into Central Quality and Business Unit Quality. The Central Quality department was responsible for quality initiatives in all the manufacturing facilities and reported to the Quality organization. The Business unit Quality organizations were responsible for resolving quality issues that developed during the manufacturing and testing of product and reported to the Operations organization. This created a conflict within the Business unit Quality department between insuring the highest quality within the product and meeting shipping schedules. The Quality department at times required work stoppage on the production line to resolve quality control issues. Work stoppages were a direct impact to meeting shipping schedules. This conflict was a direct result of the business unit Quality department reporting to the operations organization, whose primary goal was shipping.
- The Manufacturing Process Development (MPD) group went through several downsizings and was eventually renamed the Advanced Manufacturing Engineering (AME) group. The MPD group was responsible for the new process technology strategy. The MPD group was a fully staffed department that analyzed and implemented new process technology. The AME group consisted of just a few individuals and relied on the AME council for manpower. The AME council was composed of the manufacturing engineering managers and technical

specialist from each business unit. This created confusion over the ownership of new process technology coordination and a conflict in manpower between implementing new process technology and supporting manufacturing.

- Shutting down of bldg. 3, Hamilton Sundstrand's central electronics facility. Building three had been Hamilton Sundstrand's main electronics facility and had been the focus and proving ground of most of the technical and quality initiatives. With the closing of the Building three facility it was not clear who would take the lead in setting the example of high quality standards established by Building three.

In addition to the organizational changes listed above there were also a significant amount of technical changes that occurred within the commercial plastic component industry. New plastic mold compounds, reduction in the size of the packages and silicon die used, higher density[10] devices, and new die passivations were just a few of the new introductions. These changes can be characterized as technological advancements. As a matter of fact very few truly new technologies were introduced since Hamilton Sundstrand adopted the use of commercial plastic components. These technological advancements, which were being developed at a rapid pace, could be classified as improvements to the components with no obvious impact to form, fit or function of the components. In a small number of cases though these advancements created new subtle dependencies or amplified old differences that hadn't been a problem.

Quality initiatives at Hamilton Sundstrand had always been and continue to be a critical strategy in insuring high quality, reliability products. Continuous Improvements, Total quality management, and Statistical Process control were just a few of the initiatives implemented. The CEO of United Technologies Corporation (UTC) also employed a leading Japanese quality

[10] Density refers to the number of logic gates than can be processed per unit of space on the circuit die.

consultant to advise each of the business divisions within UTC on quality control. In 1999 the merger of Hamilton Standard with the Sundstrand Corporation created demands on manpower to realign and reorganize as one company. During this time the lack of manpower resulted in the Quality initiatives loosing momentum. Compounding the problem was the unfortunate passing away of the Japanese consultant during the same period. This resulted in a loss of focus on the more complex and problematic quality issues.

The impact of all these changes contributed to an increase in the customer reject rate, as stated in defects per million (DPM) and measured by products returned divided by total products shipped. Also exhibiting a similar negative trend was an increase in the cost of quality (COQ), as measured in dollars by adding material scrap, rework and repair. Reference Figure 4.1-1 Prime Customer Reject rate and Figure 4.1-2 Electronics Operations Cost of Quality below.

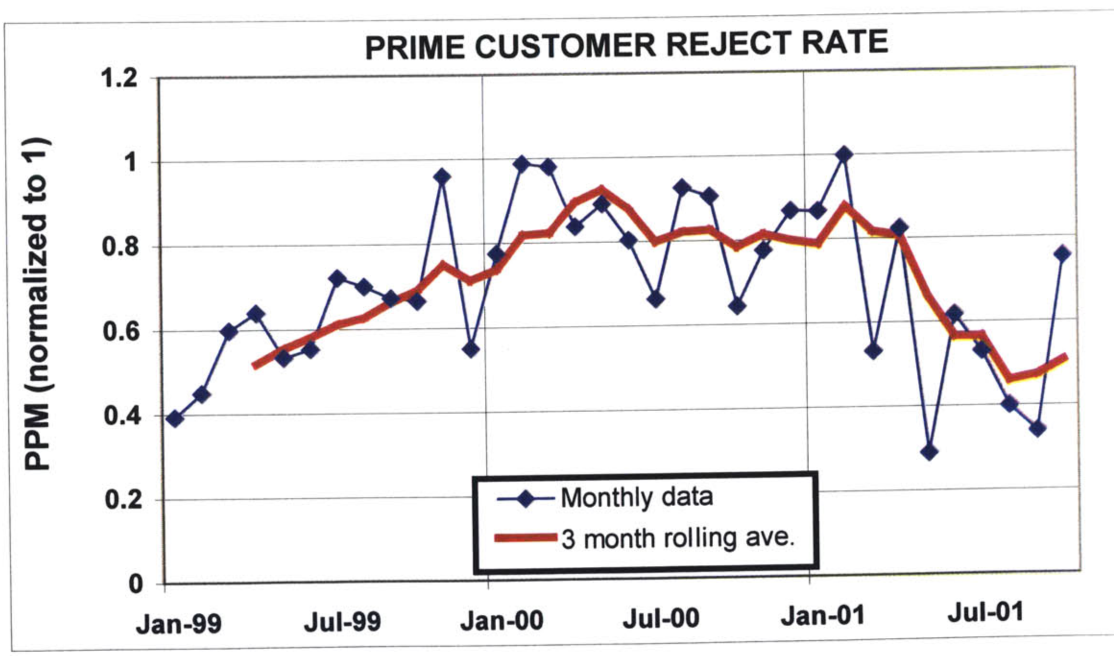

Figure 4.1-1 Prime Customer Reject rate

The graph for prime customer reject rate has been normalized to a value of one to accentuate the response of the graph over time and to remove any statistical information on actual reject rate.

The graph shows that during the time period from early 1999 until late first quarter of 2001 the prime customer reject rate continued to increase. During the first quarter of 2001 the problem received the attention of upper management due to customer feedback. A special team was assembled to immediately focus on resolving the quality problems. This team, referred to as the RED team, can be credited for the improvement seen after the first quarter. This team was still in place as of the writing of this paper (12/2001).

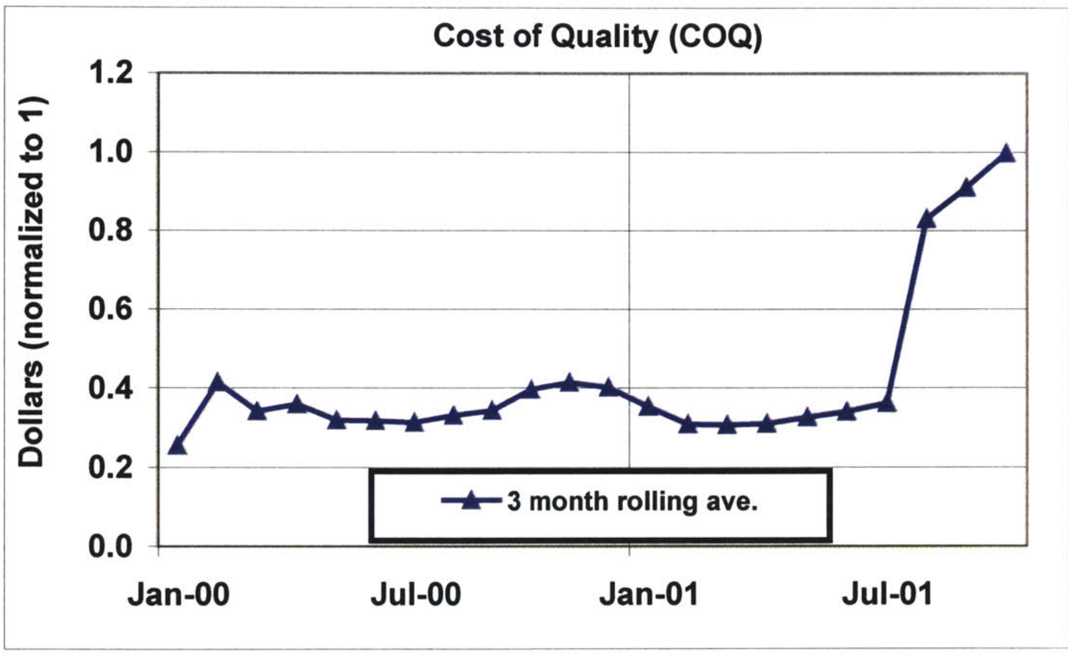

Figure 4.1-2 Electronics Operations Cost of Quality

The graph for electronics operations cost of quality chart shows that the system went out of control in the third quarter of 2001. This is a reflection of the same basic drivers seen in the prime customer reject rate. The delay in the reflection of the graph showing an increase in the cost of quality is a result of the duration of the investigations as well as delays associated with actual charge back of costs incurred during the investigation and corrective action implementation of the solution.

The research that follows will utilize boundary analysis to analyze the major boundaries involved in the implementation of the new technology initiative and identifies problems and concerns with those boundary processes that contributed to the results shown in the graphs above. First we will look at the actual implementation of plastic components. Through this analysis we will see where there were weaknesses in the implementation phase and what the outcomes of those weaknesses were. The weaknesses during the implementation phase resulted in problems that filtered responsibility down to the Failure Analysis (F/A) and Quality systems. I primarily focused on the manufacturing aspects of the initiative with emphasis on quality systems because of the direct effect it represented in driving the key metrics shown above. I could have looked at others boundaries in more depth such as design engineering but these were not as problematic since the majority of failures were related to component and manufacturing complications

4.2 Boundary Analysis: New Technology Boundary

4.2.1 Boundary

New technology resulted in a pragmatic boundary that would require a new language, new procedures and new solutions. The pragmatic boundary created by the implementation of the commercial plastic component initiative consisted primarily of the following functional groups:

- Components Engineering – responsible for component standardization, new component technologies, and parts list approvals.
- AME – responsible for the research and development of new process technologies.

- Manufacturing Engineering (ME) – responsible for the development and control of manufacturing and testing processes of electronic products manufactured by Hamilton Sundstrand.
- Failure Analysis department- responsible for the analysis of component failures.
- Suppliers – manufactured the commercial plastic components. Also responsible for helping to resolve component issues experienced by customers. Included in the same function with suppliers were the brokerage houses (brokers). Brokers sold parts that were not purchased through normal distribution channels. These parts were typically procured from second hand suppliers who were liquidating excess or obsolete inventory. There was a much higher concern over the reliability of parts procured through these sources. The use of brokers was much more prevalent with commercial plastic components then it was with military ceramic components. Brokers did not support investigation of component failures experienced by customers.

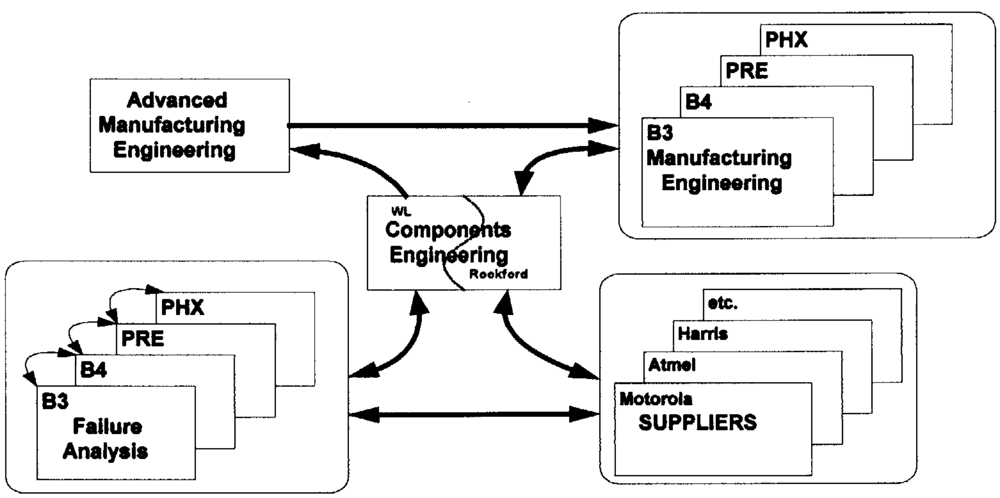

Figure 4.2-1 New Technology Boundaries

Figure 4.2-1 New Technology Boundaries above shows the interactions between the functional groups. As can be seen from the graph, components engineering held the most central roll in coordinating the implementation of commercial plastic components. The primary function or goal in the implementation of commercial plastic components was to provide a competitive advantage. The primary function and goal of the groups supporting the initiative was to develop a new manufacturing process that would accommodate designs with both commercial plastic and military ceramic components. Manufacturing cost and quality were key parameters in this implementation. Although Hamilton Sundstrand's customers were beginning to accept the use and advantages of commercial plastic components, military ceramic components would still represent a significant percentage of the components assembled into hardware for years to come.

The boundary created by the new technology insertion was very complex. The technology involved was very new to Hamilton Sundstrand and the interactions the new technology would create with each of the functional groups would be significant. There was a high degree of functional specialization within many of the groups that made the exchange of knowledge difficult. New sources of novelty being introduced were very high. This assessment needs to be qualified. When evaluating the amount of novelty introduced over several years there were many organizational changes within Hamilton Sundstrand and technological advancements within the plastic component industry occurring. If you were to evaluate over the time frame of a development program, which concentrated the majority of activity into a period of less than one year, the amount of novelty might be perceived to be much less.

Time was probably one of the most critical issues in driving boundary complexity. Once the research and development had been completed and the decision was made to proceed with commercial plastic components, the implementation would occur on the next program being developed. By implementing the new technology on a production program instead of a pilot program you were limited in the amount of time available. Also, special teams, resources, and priorities were only in place to implement the new technology and to create some momentum behind the initiative. Once the new technology was in place and functioning on a program the resources were dissolved and the long-term responsibility was folded back into the regular functional groups. This meant that the original participants would not directly perform long-term validation on implementation or have the opportunity to improve experience or efficiency through iteration of the process.

4.2.2 '3-T' Framework

Requisite Variety: During the research and development of commercial plastic component technology several engineers were sent to extensive training. Through this training Hamilton Sundstrand was able to develop extensive requisite variety to be able to identify differences and dependencies in the existing processes. One disadvantage to the training was that the majority of people trained were from the components engineering department. Component engineering was a central organization that had regular interaction with all the functional groups. In this fashion they were the most well rounded technically. Their central role was to disseminate this training to the other functional groups as required. By not requiring each functional group to directly receive the training it limited the amount of critical analysis performed by each group. Although components engineering would train each functional group, the training would carry the biases and priorities of the components engineering group. Even though the Components Engineering was highly specialized in new component technologies, what was relevant to them may not be all that was relevant to other groups involved. This resulted in information being lost or discarded whose impact to groups outside of components engineering was not clearly understood. Once the initial training had been received and disseminated there was no other formal training, partnerships or procedures put in place to promote the continued development of requisite variety within the commercial plastic industry. The responsibility to cultivate training and development programs defaulted to the individual functional groups. This was not clear and most groups continued to look towards the Component Engineering group for their training. The result was a lack of tools or processes to developed requisite variety or to transfer the knowledge that was being developed. The negative boundary consequences would affect Hamilton Sundstrand's ability to effectively resolve and coordinate new sources of novelty.

Syntactic: Through years of using military ceramic components Hamilton Sundstrand had built a sufficiently large and tested syntax that was a very effective tool in transferring knowledge. Because of the comprehensive similarity between commercial plastic components and military ceramic components much of this language was still applicable. What additional language had been required was identified and developed during the research and development phase when training and teams were very active. This language dealt with the specifications of hardware but did not deal with the latency of problems created by differences in the sources of novelty or differences in the services provided. The negative boundary consequences limited the effectiveness to plan and adapt to these new sources of novelty.

Semantic: Similar to the syntactic condition the semantic language and tools were adopted from the military ceramic processes. The new process involving plastic commercial components used most of the same equipment, same processing, same assembly tools etc. There were differences, such as handling and storage had to be more controlled, but these were quickly identified and new agreements (modified processes) were easily made. Although a sufficient process was developed it was not properly documented. Many of the differences and dependencies identified resulted in the new agreements, modification of existing procedures or the creation of new ones. Listed were the new agreements but not the reasons or consequences of the new agreements. This oversight would eventually result in problems as the initial boundary users who held this knowledge moved on to different positions. The new agreements would then be modified without understanding the impact because the negotiation of trade-offs and consequences involved in the previous agreement were not captured and therefore could not be re-used in the next cycle. As an example, solder reflow of commercial plastic components is very critical. If the soldering temperature is to high it may stress the component, if the temperature is too low it may result in a poor solder joint. When plastic parts were implemented this dependency on temperature and difference in extremes was identified and soldering procedures were modified to reflect the new temperature. The new agreement was clear, the establishment of a new temperature, but the reason, consequences and trade-offs of package reliability and solder joint reliability, was not captured within the agreement (new procedure). Over time the people who understood the dependency moved to new positions and were replaced. Their replacements, not clearly understanding the differences, raised the soldering temperatures. This was done because of the lack of a boundary object to represent the differences of temperature on package reliability and solder joint quality. The new users were primarily focused on the dependence they knew, which was raising soldering temperatures resulting in improved solder joint quality. The consequence was improved solder joint but higher stress on the component package.

Pragmatic: The implementation of plastic parts represented a significant change from existing processes resulting in a pragmatic boundary. Although there were many similarities to military ceramic components there were still many new solutions that had to be developed.

When these solutions were developed within a team environment, such as existed in the research and development phase of implementation, the decisions made were well coordinated with all functional groups to insure that dependencies and differences were identified and trade-offs were negotiated. The teams created to implement plastic components were valuable boundary tools. Their consistent membership, focus and process to negotiate trade-offs resulted in effective solutions. When these teams were dissolved they did not capture the knowledge of the process they used or the lessons they learned. As the responsibility was shifted to individual functional groups the pragmatic solutions developed in the team context were not followed and the boundary began to degrade. Over time as new sources of novelty were introduced and new dependencies and differences were created, individual functional groups were not effective in making local decisions due to their global impact. Also, the tools did not exist which could model these differences and dependencies so that trade-offs could be explored without requiring the creation of an integrated engineering team. The following example of the use of brokerage houses will help to illustrate this point.

The use of brokerage houses was a novel solution to the situation of component shortages. In the commercial plastic industry the priority of service is proportional to the volume of components ordered. Since Hamilton Sundstrand used very low quantities of parts their service priority was very low. This resulted in component manufacturers occasionally missing shipments of parts. Missed shipments would create a component shortage causing the assembly floor to be impacted. The purchasing departments use of brokerage houses would sometimes avoid component shortages by allowing purchasing to fill the shortages with components purchased from the brokers. This came at a cost though, as brokerage houses would charge a much higher component price. The problem this created was the dependence that this solution had with other departments such as operations, quality control, components and failure analysis. Were the parts reliable? Did they need additional testing? What was the additional cost to buy the parts vs. the savings to operations by avoiding the shortage? The trade-offs were never evaluated and the result was a solution that created as many problems as it was intended to solve.

Boundary Objects: There were many boundary objects that were used to promote the transformation of knowledge across the boundary. IPD team, Component reliability reports, which tracked usage of plastic components, Failure analysis reports, and production change notices (PCNs) were just a few of the boundary objects utilized. Boundary objects, such as repositories, that shared a common language/syntax were very effective. The syntax was stable and the knowledge was available to all functional groups. Most repositories were not directly accessible though, which added delays and inconvenience when retrieving information. When the knowledge to be transferred required a semantic approach the boundary objects, such as standard work or shared methods, tended to capture the new agreements negotiated but not the reasons (dependencies, differences) that resulted in the new agreements. This resulted in the objects degrading in their effectiveness over time as new sources of novelty and new boundary users were introduced into the system. When the knowledge to transfer required a pragmatic approach success was very dependent on the individual or team involved in the process. The tools to model dependencies and explore differences did not exist and were critically needed. When an experienced team (specialists) was assembled to manually perform this activity the solution was much more effective. When individuals or inexperienced teams were tasked with creating the solutions they were not as effective in managing the boundary between the team and the functional groups. This reduced their ability to capture the dependencies and differences and negotiate trade-offs therefore resulting in solutions that were less effective.

Boundary Effects and Barriers: Examples of some of the barriers experienced in managing the boundary created by new technology implementation were:

- Technological complexity
- Rate of novelty being introduced (both organizationally and technologically)
- Lack of resources once the new technology was implemented
- Reluctance of some functional managers to accept the new technology

By far the most problematic barrier though was falling into the 'competency trap' due to path dependency. Commercial plastic components were very similar in form, fit and function to military ceramic part. This high level of dependency [apparent similarity, minimal difference] made it very easy and efficient to re-use a majority of the processes developed previously with military components. We had developed the competency with the military processes and it would be easier if we could re-use most of the same processes. The problem was that insufficient time and energy was devoted to researching the differences that existed to insure the processes were sufficiently modified, or were discarded if they were no longer applicable. Competency is only good if the 'task' doesn't change or no new sources of novelty have arisen. The following section will help to illustrate two examples that resulted in Hamilton Sundstrand falling into the competency trap.

Hamilton Sundstrand was very good at dealing with suppliers based on their experience from purchasing military components. Hamilton Sundstrand and their suppliers developed and shared the same syntax and semantics. With the switch to commercial plastic products they fell into a competency trap. The same processes were used because the component specifications were the same and most people thought 'how different could buying commercial plastic components be?' In most cases the same suppliers were used, although plastic components were manufactured at different facilities. Hamilton Sundstrand and the suppliers had developed a shared syntax/semantics around the technology that hadn't change significantly. What Hamilton didn't realize was how different the semantics would change for the service side of dealing with the suppliers. Cost, quality, volume, root cause had the same definitions but very different meanings for the commercial suppliers vs. the military suppliers. Quality and root cause were the main priority of the military manufacturers (and Hamilton) while cost and volume were the main priority for the commercial manufacturers. Hamilton Sundstrand was very slow in recognizing this and continued to use processes that were less effective negotiating the new boundaries with commercial plastic manufacturers.

Another competency trap developed when novelty occurred over a long period of time. The novelty was being introduced from rapid technological advancement. Individually the impact of each advancement was minor but over time, due to its rapid rate of development, it created significant differences. As mentioned earlier the appropriate models were not developed to be able to analyze this change. Due to the novelty introduced, what had started out as an efficient process for dealing with a known boundary eventually degraded into a process that was no longer as effective. It happened over such a long time period (typically 1-3 years) that people didn't realize it. The trap becomes set and we are left with trying to develop new solutions with the old process.

4.2.3 Dynamic perspective

The rate of novelty being introduced into the system was high. Technological advances were occurring every several months with organizational changes happening at a slightly slower rate. This placed a burden on the system to iterate at a faster rate to be able to evolve and adapt to this change. During the implementation phase of commercial plastic components the process iteration level was sufficient to support this level of novelty introduction. As the implementation phase concluded the responsibility passed down to the individual functional departments. Although there is process iteration at the functional (local) level it is not involved enough to be able to assess the overall (global) effectiveness of the commercial plastic component initiative process. The integrated development team assembled to coordinate the implementation of commercial plastic components coordinated the entire global process of the commercial plastic component process. The functional groups were looking only at their responsibility in the process. As new sources of novelty were introduced the dependencies and differences affected many groups and required coordination at a higher global level and not at the individual functional level. This has resulted in an iteration rate at the system level of zero since the completion of the implementation phase. When the 'RED Team' was implemented to identify the reasons for the increase in cost and quality defects they were tasked with evaluating the entire system. This can be considered the first iteration at a global level, as the team was looking at the effectiveness of all processes and interactions involved. With many processes observed at Hamilton Sundstrand this was the method of iteration that was typically used. Effective, system level iterations were ad-hoc and were usually preceded by a negative event that lead management to initiate them

4.2.4 Knowledge representation

Much of the knowledge from the implementation phase was intended to be captured in procedural documents that would define the process. Several documents that were created are still in existence today. The knowledge captured within these documents unfortunately only describes the end state and does not describe the steps taken to arrive there or the reasons that they were chosen. Because of this the documents represents more of a historical reference then knowledge representation.

When the program to implement commercial plastic components was coming to an end no time was dedicated to capturing the knowledge that was generated. Most of the knowledge that was developed during the implementation phase remained tacit. Over the years as people moved into new positions what little knowledge they passed on to their successors was all that remained. At the beginning of the program a significant amount of time was spent retrieving knowledge in the form of training, data searches and benchmarking. This knowledge as well was collected but did not have the proper resources planned to insure it would be captured, formatted and stored for future use by the functional groups that would receive responsibility for maintaining the successful implementation of plastic components.

The failure to capture the knowledge generated during the research, development and implementation of the new technology meant that there was only limited tacit knowledge that existed to define the dependencies and differences identified. This resulted in lessons learned having to be relived, knowledge having to be re-generated and solutions being developed with insufficient knowledge to understand their full impact or effectiveness.

4.2.5 Discussion

The implementation of commercial plastic components was very successful. The initial program met with few complications and achieved most of its goals. Critical to that success was in keeping the same team together that researched and developed the commercial plastic part initiative, to implement it on the first program. The requisite variety, knowledge, and tools were all in place to minimize barriers. As the success was repeated in the second program the team began to dissolve as responsibility to maintain the plastic part initiative feel back to each functional group. The implementation team was managing the primary boundary created by the new technology. This team maintained global responsibility coordinating the sub-processes and boundaries, such as failure analysis and quality control, as well. When the team dissolved the need to manage the primary boundary still existed due to the new sources of novelty being introduced. Unfortunately the functional groups were not aware of the complexities involved. The level of novelty being introduced and the global impact the novelty had was still not clearly understood within the departments. Requisite variety was not planned for allowing path dependencies to dictate inefficient solutions, procedures lacked semantic information to clearly identify and communicate differences and dependencies, the tools to negotiate these differences didn't exist and the knowledge and lessons learned during the development of the processes was never captured. This resulted in problems that the functional groups have had difficulty solving and has led to reliving previous lessons learned. The following two sections will look at two additional functional boundaries of failure analysis and quality to provide further insight into the boundary analysis provided on the insertion of new commercial plastic component technology.

4.3 Boundary Analysis: Failure Analysis

4.3.1 Boundary

The new technology of commercial plastic components created a pragmatic boundary that needed to deal with new sources of novelty. The implementation team was created to deal with this pragmatic boundary. Unfortunately the team developed a rigid, static process that could not effectively adapt to the novelty being introduced. When the implementation team dissolved the responsibility for coordinating new sources of novelty was passed on to the individual functional groups at the boundaries. This resulted in the responsibility for the on-going coordination of the new technology falling into the boundaries created by the processes of failure analysis and product quality control.

The failure analysis process was responsible for the investigation, root cause determination and corrective action recommendation of failed components. The failure analysis process was used reactively to identify component problems. With commercial plastic components the failure analysis process provided a reactive means to identify new sources of novelty whose dependencies and differences were not clearly understood and were resulting in failures. The boundary created by failure analysis resulted in a primarily semantic boundary type. Although failure analysis dealt with many new sources of technological change it was not responsible for resolving these new issues. The failure analysis process was primarily responsible for identifying and understanding the causes and technical reasons behind the failures. This resulted in the process being very stable. Experience and technical capability were very important but these were not pragmatic. The major responsibility of the failure analysis boundary was to exchange knowledge developed during investigations that represented the dependencies and differences of the novelty introduced. This is representative of a semantic boundary. The failure analysis boundary consisted of the following functional groups:

- Initiator- this was the functional group or individual that identified the failure and submitted the component to the failure analysis department. Manufacturing Engineering submitted the majority of component failure analysis requests.

- Failure Analysis departments- each business units maintained their own failure analysis lab. The F/A dept. performed the analysis, determined root cause and suggested short-term corrective action.
- Quality Engineering- responsible for quality control and to support failure analysis investigations. Included as part of the responsibility of investigations was the coordination and implementation of short-term corrective developed as part of the failure analysis investigation process.
- Component Engineering- coordinated new component technologies. Monitored reliability and took action if requested by the F/A or Quality dept. to resolve component issues.
- Suppliers- manufactured the commercial plastic components. They were utilized to assist in the investigation of components they manufactured that failed.

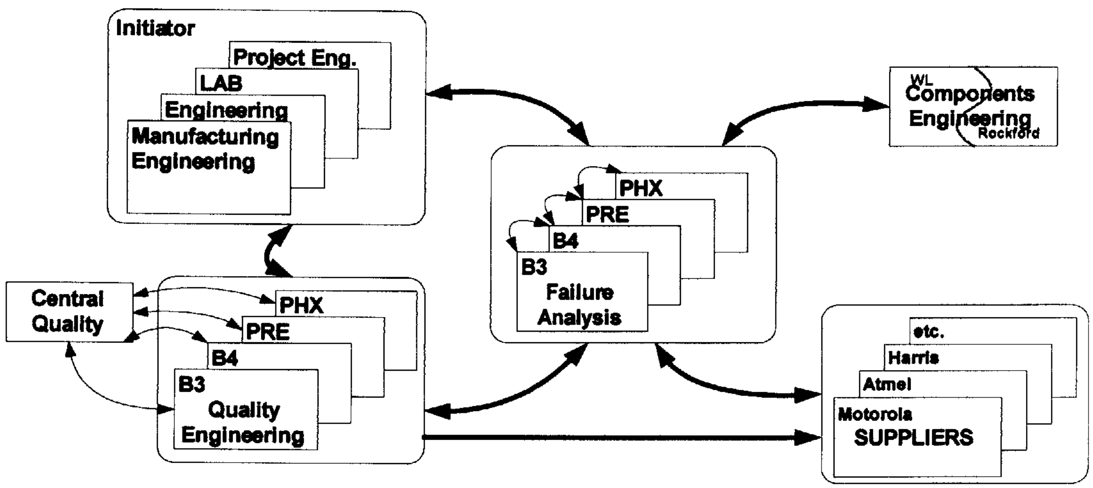

Figure 4.3-1 Failure Analysis Boundary

The primary function of the failure analysis process was to rapidly analyze a component failure to determine root cause and then, through additional research, recommend corrective action. The corrective action would be submitted to the quality department to determine short-term corrective action. Long-term corrective action and process modification would be conducted as part of the quality control process. The root cause would be submitted to components engineering if supplier action or component restrictions were required, i.e. if new sources of novelty impacted the way we were using, purchasing or testing components. Once this was complete the cause of the failure would be shared with the other failure analysis labs and business units as a lesson learned to be incorporated as the business unit saw fit.

Boundary complexity was high primarily due to the level of specialization that existed at the boundaries. Failure analysis was highly specialized with only minimal understanding from other functional groups of the roles and responsibilities of the failure analysis depts. Also, each business unit was specialized to some degree in their manufacturing processes. This was a result of allowing independence in the way that similar manufacturing processes were allowed to deviate in implementation, operation, and maintenance from business unit to business unit. This resulted in specialization perceived as differences when in reality it represented a high level of dependence with only small degrees of separation.

4.3.2 '3-T' Framework

Requisite variety: During the implementation phase of commercial plastic components the failure analysis dept., which holds primary responsibility for technical boundary issues, received thorough training. This developed the strong initial requisite variety. Over the years, as novelty was introduced, the level of requisite variety continued to develop as part of the learning process during component investigations. During the last several years workforce reductions and attrition had left the failure analysis dept. understaffed. As a result, the time available to learn about new sources of novelty and to develop the requisite variety needed to maintain efficiency became limited. This resulted in reliance on the suppliers for the requisite variety necessary to fully define dependencies and differences. This new boundary was less efficient because the suppliers did not fully understand Hamilton Sundstrand processes. The lack of requisite variety developed by the failure analysis dept. also trickled down to other functional groups that relied on them to provide the necessary training to develop their own knowledge and experience. As the failure analysis dept. was developing less requisite variety, less was being passed on to other functional groups impacting their ability to handle new sources of novelty.

Syntactic: Through years of using military ceramic components Hamilton Sundstrand had built sufficiently large and tested failure analysis syntax. This same syntax was used as the basis for transferring knowledge with commercial plastic component failure investigations. To handle new technologies representative of commercial plastics the syntax was enhanced to include new language definitions. Several problems existed with the new syntax. First, although a syntactical language was created it was very specialized. Because of the specialization, it simplified the exchange of knowledge between failure analysis depts. but made it difficult to share this knowledge with other functional groups. As a result, knowledge transfer between the initiating groups and the failure analysis labs was poor and resulted in large amounts of knowledge being lost. Also, because of the specialization of the language it resulted in some 'localization' within each of the business units. This can be equated to the same language developing different dialects when groups of people are separated by geographical boundaries. In Hamilton Sundstrand's case each business unit was geographically dispersed and therefore developed a syntax that was slightly 'localized' to their culture. This resulted as well in the loss of information. Finally, when the syntax was developed with the use of military components the users developed a syntactical language that was sufficient for the environment in which they were operating. This meant that the language was detailed enough to understand the problems being investigated. With the implementation of commercial plastic components came the need to update the language to the new technology. This was done. What wasn't realized was that commercial plastic components would bring a different set of failure conditions that would be much more problematic than anticipated. This new source of novelty would require the development of new syntax to effectively transfer the knowledge between boundary participants. This has been slow to develop and therefore has hindered the exchange of knowledge

Semantic: As mentioned above the transfer of knowledge suffered from insufficient syntax. When the knowledge being transferred was from failure analysis dept. (highly specialized in commercial plastic) to failure analysis dept. the focus has been on developing a semantic boundary built on top of the existing weak syntactic boundary. They have identified the dependencies and differences realizing the benefits of the dependence and the concerns over the differences. They developed tools and objects with which to address these semantic issues but are limited in the effectiveness of knowledge transfer due to the lack of a sufficient syntax. When the case is of knowledge being transferred between the failure analysis lab (highly specialized in commercial plastic) to initiator (generalist in commercial plastic) the problem of a weak syntactic boundary inhibiting the semantic boundary is much more severe. The lack of a well-understood syntax severely limits the understanding of dependencies and differences that must be developed to properly transfer knowledge. Because of this the initiator continues to exchange only that knowledge which they are aware off. Only through iteration does the initiator improve their understanding of the syntactic and semantic boundary tools and language as experience is developed through lessons learned. Training has been attempted to develop this experience but resulted in only limited improvement.

Pragmatic: Failure analysis was not considered a boundary dominated by pragmatic issues. The failure analysis process was a very stable and consistent process. The problems encountered and the root causes involved may have been novel but this was not considered problematic. Within the process of failure analysis are embedded steps that involve developing the requisite variety required to understand the novelty of the component failures being introduced. With this understanding, the development and transfer of new knowledge is not a matter of developing new pragmatic solutions but rather a situation of developing new syntax and semantics to deal with the new sources of novelty. As will be seen later, the pragmatic boundary falls upon the quality boundary to resolve the issues of novelty.

The one pragmatic issue that was identified was the increasing novelty being introduced internally due to changes in workforce, organizations and cost pressures. High workforce volatility, changing organizational control and increasing pressures to improve performance has required new novel solutions to meet these new challenges. This will be problematic, as it will require new syntactic and semantic boundaries to build the pragmatic boundary upon. This is the result of having to look at novel sources of knowledge such as outsourcing, joint ventures, partnerships and other avenues that have not been used in the past to the level required to meet the new challenges.

Boundary Objects: There were many boundary objects identified during the review and research of the failure analysis process. Each lab and business unit maintained their own repositories to capture the knowledge being generated and exchanged. The repositories were all locally maintained and provided access only to owners. This resulted in the data being highly localized and not easily shared once it had been stored. Even more critical to the data was the lack of a sufficient syntax with which to transfer knowledge. This resulted in minimal transfer of knowledge and value to other groups. Most of the time the data was seen as independent because the common language developed looked at the technology only from a high level. Had a more detailed common language (syntax) been developed more dependencies could have been identified resulting in greater value in the sharing of knowledge.

Semantic boundary objects were numerous but with limited success in their intended role of improving the transfer of knowledge. Input forms, standard reports, training modules and standard procedures were some of the objects used in an attempt to reduce the complexity faced by generalists having to understand and transfer knowledge with specialists. The main problem with the objects and tools were that they were developed by the specialists to be utilized by the generalists at the boundary. This limited the amount of ownership and responsibility felt by both parties and resulted in only sporadic effective use of the tools.

Boundary Effects and Barriers: The main boundary effect that prohibited the transformation of knowledge was the level of specialization of the failure analysis dept. Failure analysis is a relatively new discipline that is highly technical but not widely taught. Most Failure Analysts developed the skills of their trade on-the-job. This specialization lead to a lack of understanding of the roles and responsibilities in the type, amount and content of knowledge that was required for failure analysis. Additional problems were created by the lack of consistency and frequency of use of the failure analysis boundary by generalists. There were many generalists who were users but very few who repetitively worked across the boundary. The greater the level of iteration by an individual the more effective they have been at transferring knowledge. The effective transfer of knowledge was reciprocal across the boundary, i.e. they more effective initiators were at inputting failure data the more improved the investigation results would be that they received back.

4.3.3 Dynamic perspective

Validation for the failure analysis boundary was very difficult because it was not clear what metric would be representative of an effective boundary. The result was boundary users that selected local metrics that represented how well they were doing as an individual group but did not accurately represent the effectiveness of their sharing and transforming knowledge with other functional groups involved in the failure analysis process.

In a review of processes to coordinate the transfer of knowledge the value of the knowledge being transferred was never defined or measured. Extensive time and resources were being taken to generate the knowledge and to capture it but the value of the knowledge was never estimated, measured or quantified. Each user considered most of the knowledge to be of some value but not all of the knowledge to be of value. The cost effectiveness of the knowledge was never validated. As an example as mentioned earlier anyone could be an initiator. Forms were created to aid the initiator in identifying and transferring knowledge. An important metric could have been established to measure the effectiveness of the inputs. This data could have been compiled from the tracking of how thorough the input forms were filled out. This process validation was never implemented because it was not clear what the value of having accurate, thorough input information would be and therefore what priority this task should receive.

Iteration was not an issue due to technological novelty being introduced to the system but was an issue due to the amount of organizational novelty. The lack of consistent iteration resulted in limited learning and experience being developed as a result of the repetitive execution of the process. By having different users within the system no one individual would iterate the process a sufficient number of times to gain the experience through problems and lessons learned from previous iterations. This perpetuates the problem of lack of understanding of the specialization involved and therefore lack of understanding required in the process of transferring knowledge.

4.3.4 Knowledge representation

Knowledge capture was a critical part of failure analysis. The knowledge captured represented requisite variety developed in the area of component technology, supplier quality, manufacturing dependencies and failure analysis techniques. The data from the failure analysis investigations was considered valuable and the chance of re-use considered high, although this was never attempted to be quantified as part of the valuing process. The process for storing failure investigation data was inconsistent and time was never directly identified during the failure analysis process. This resulted in a large number of databases locally stored by each of the individuals coordinating the investigation. 'Local' storage of data created retrieval and transformation problems. Lack of common syntax/semantics also made retrieval on a local level problematic. As an example the main repository for capturing knowledge were the failure analysis databases that stored the failure analysis reports. These reports were generated by the Failure Analysis depts. and captured most of the technical issues involved in a failure investigation. These reports were highly localized by the failure analysis dept. and did not capture clearly critical information from supporting groups such as Quality Engineering, Supplier Development, Reliability, etc. This reduced the ability to recreate knowledge developed during previous investigations.

The level of novelty being introduced into the system was not a critical factor to making stored knowledge obsolete. Most technological advances were not destructive technologies but rather built upon or improved previous innovations. This allowed the knowledge to retain its value for long periods of time in most of the commercial plastic components being developed. Also, the knowledge captured represented an excellent learning tool for new users and employees. The requisite variety would come from sharing data within the lab, within HS labs and within UTC labs.

The use of supplier failure analysis labs and outside labs provided another critical need to capture knowledge from investigations. The process of using supplier labs and outside labs is repetitive but with potentially long cycle times (slow iteration rate). The cycle has minimal change resulting in only an occasional supplier/lab facility closing or workforce turnover. By capturing knowledge from previous investigations involving these resources it has helped to develop an understanding of capabilities (dependencies and differences) of these resources so that knowledge transfer and transformation can develop more efficiently in the absence of a high rate of iteration. Knowledge capture in this case was important to be able to manage the new boundary created.

4.3.5 Discussion

Failure analysis is a reactive process that provides an opportunity to identify new sources of novelty being introduced. Because of the reactive response to problems it is very critical that investigations are conducted rapidly and that minimal recurrence of defects occur. The boundary created by failure analysis was characterized more by a dependence on syntactic and semantic boundary types. The weak development of the syntactic boundary created problems that were amplified when users were faced with the development of a semantic boundary built upon the syntactic boundary. The syntax not developing a common language on which to develop dependencies and differences resulted in some knowledge not being transferred and inhibited the effectiveness of transforming the remaining knowledge into new, valued solutions.

Additional problems were created when insufficient manpower was present to man the boundaries. The lack of manpower in the failure analysis lab resulted in a rippling effect from not developing sufficient requisite variety during investigations. This led to a dependence on the use of suppliers for their knowledge and experience. Suppliers who did not have the full understanding of Hamilton Sundstrand's operations and processes. This resulted in misrecognition of the more subtle dependencies and differences of commercial plastic components with Hamilton Sundstrand's manufacturing process. Also, by the failure analysis lab not developing the requisite variety during investigations and sharing this knowledge with other functional groups the result was failure investigations that became path dependent and lacked sufficient requisite variety to handle true root cause identification.

Finally, due to a lack of a sufficient validation process, metrics did not clearly indicate the degradation of the boundary. Metrics were chosen locally and showed internal improvements at the same time that the system level operation was degrading. This was aggravated by the fact that the value of the knowledge being generated and transferred was not quantified to determine the cost effectiveness. This would have allowed the focusing of resources and processes to the functions of generation, storage and retrieval of knowledge that represented the greatest value to Hamilton Sundstrand.

4.4 Boundary Analysis- Quality

4.4.1 Boundary

Quality control was responsible for insuring the quality and reliability of the products produced at Hamilton Sundstrand. Most of the knowledge transformation that had been coordinated by the implementation process ended up being pulled into the boundary created by the quality control process. This boundary consisted primarily of the functional groups from:

- Quality Engineering- responsible for quality control and the long-term corrective actions developed as part of the failure analysis investigation process.
- Failure Analysis depts.- responsible for technical analysis and short-term corrective action.
- Manufacturing Engineering (ME)- Responsible for the implementation of corrective action that impacts the manufacturing processes.
- Component Engineering- coordinated new component technologies. Monitored reliability and took action if requested by the F/A or Quality dept. to resolve component issues.
- Suppliers- manufactured the commercial plastic components. They were utilized to assist in the investigation of components they manufactured that failed.

Figure 4.4-1 Quality Control Boundary below shows the interactions between the functional groups. As can be seen from the figure the Quality Engineering and Failure Analysis groups held the most central roles in coordinating the quality control process.

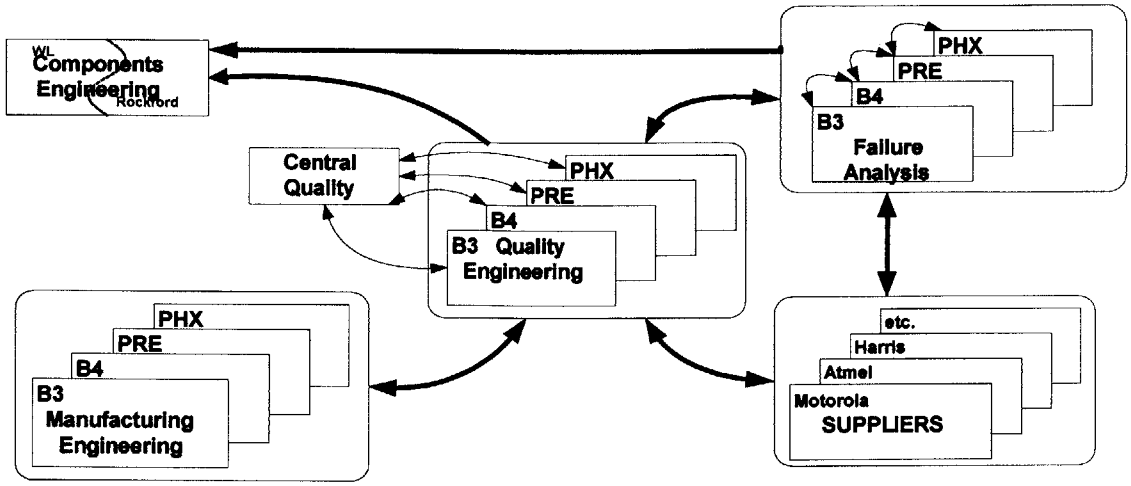

Figure 4.4-1 Quality Control Boundary

The primary function of the quality control process was to identify and resolve component issues. This was done reactively after a problem or defect had been identified. Once the problem was identified Quality Engineering would work with the Failure Analysis labs to identify the root cause of the failure and short-term corrective action. The long-term corrective action was more problematic and typically required additional coordination with the Suppliers, Manufacturing Engineering, and Components Engineering.

The boundary that formed around the process of quality control was complex and very pragmatic. The pragmatic boundary was a result of being faced with many sources of novelty that required new novel solutions. Unlike the boundary created by failure analysis, which required short-term generic corrective action, quality control required long-term novel solutions to insure effective closure. The complexity of the boundary was driven primarily by the novelty being introduced into the system and the quantity of knowledge required to coordinate and generate solutions. The clockspeed of technological advancements within the commercial plastic industry was high with many changes occurring on a yearly basis. Organizational changes were just as high with management chains and workforce levels changing several times a year[11]. The quantity of knowledge that was required to coordinate and generate solutions was very high. Knowledge was also required from multiple sources to generate cost effective solutions. Solutions were dependent on receiving accurate, timely data from several sources. Most of the data was not specialized and therefore did not add to the complexity. Much of the complexity was driven by understanding what data was needed and when. Each investigation would require different types of data depending on the source of the defects and the impact of failures. This variation in the knowledge required made it difficult to consistently and efficiently transfer knowledge (on time and accurate).

4.4.2 '3-T' Framework

Requisite variety: Sufficient requisite variety had been established over the years and was not a limiting factor. As mentioned in the discussion of the failure analysis boundary the development of new knowledge was primarily developed during the failure investigation and then transferred as required to functional groups that participated in the quality control process. The failure analysis process worked at a much more detailed level and therefore relied more heavily on developing the requisite variety. The quality control process worked at a much more general technical level but required greater quantities of data. This required a greater understanding of organizational functioning to understand where the knowledge was being generated. As will be covered in greater depth later, the development of weak solutions was more a result of falling into a 'competency trap' and a lack of validation to recognize the

[11] Organizational changes were very high at the end of the 1990's and early 2000 due to growth through acquisitions and mergers.

ineffectiveness of solutions then it was not having the requisite variety to generate new, novel solutions.

Syntactic: Through years of using military ceramic components Hamilton Sundstrand had built a sufficiently large and tested syntax that was a very effective tool in transferring knowledge. Because of the similarity between commercial plastic components and military ceramic components much of this language was still applicable. Novelty being introduced was more of an impact to the technical process of failure analysis but resulted in minimal changes for the quality control process. This resulted in a very stable, sufficient syntactic language that was common among functional groups and held very little change over geographical boundaries.

Semantic: The failure analysis process placed more emphasis on semantics to try and promote the exchange of knowledge. This lead to the development of a weak syntactical language that was not able to support the transformation of the information into value added knowledge, reference section 4.3.2. The quality control process suffered from the opposite effect. The syntactical language was sufficiently developed but very little effort was placed on developing the semantic boundary. Information was required from many different sources and was shared with many different functional groups and business units. Exchange of information was a semantic issue where the differences were identified and then allowed to dominate the boundary. The dependence was due to the same equipment and manufacturing strategy while the difference was due to localized designs and processes. The differences were identified but not clearly defined to allow the value in the dependencies to be recognized. People looked at the differences in the boundary and assumed, because they can't be easily altered or minimized, that it will affect the data and leave little to no value in supporting the exchange of knowledge. Many sources of knowledge were not being developed, or shared knowledge at a lower rate than was available. This resulted in a reduction in the quantity and quality of knowledge available at the boundary.

Pragmatic: The boundary created by the quality control of commercial plastic parts was very pragmatic. Although commercial plastic technology was similar in many ways to military ceramic, the failures that resulted in commercial plastic were much more problematic. At a pragmatic boundary to create new knowledge and solutions old knowledge has to be transformed. The new sources of novelty were not recognized leading users to follow the old processes and procedures.

Suppliers were not as responsive to implement additional quality control. The high volumes of supplier manufacturing meant more defects were created when problems did occur and the physics of the failures themselves were more problematic because of the encasement of the die in plastic. Competency traps resulted in trying to solve new problems with the old knowledge and syntax. This resulted in many ineffective solutions that have only increased the latency[12] of the failure (how long it takes Hamilton Sundstrand to detect the failure) or increased the number of recurring failures. Recurring failures are very challenging because they are resolved short-term, leaving the impression that the solution was effective, only to have the failure re-occur several months or years later. Recurring failures have been a pragmatic issue because Hamilton Sundstrand has not been able to solve the failures and has not recognized the need for more progressive (novel) solutions. A portfolio of options must be available to create the right solution for the right problem. Recurring failures that are impacts to cost and quality or are a concern of the customer must be addressed in a way that provides new solutions to fit the customers' needs. Making the right decisions is based upon having sufficient knowledge from

[12] Latency was a term used to characterize defects indicating a component that would operate for a significant time before failing.

multiple sources and being able to perform trade-offs of consequences to evaluate the effectiveness of old solutions or the need to generate new, novel solutions. Knowledge being shared is typically incomplete or delayed and the process for negotiating trade-offs is done manually and therefore dependent on the skill and experience of the individuals involved for its effectiveness. Also, as new, novel solutions are generated this impacts other boundaries such as those created with the customer or suppliers. This will require modifying the syntactic and semantic boundaries to insure the novel solutions are understood and accepted. The result is an increased burden on the already weakly defined semantic boundary.

Boundary Objects: Objects and tools that were used to facilitate the transfer of knowledge across semantic and pragmatic boundaries were minimal. Modeling tools to allow the evaluation of trade-offs and to explore different scenarios and consequences did not exist. This task was left to investigative teams to evaluate and was considered to complex and knowledge dependent to be effectively coordinated without information processing tools. The investigative teams were not formally chartered and existed only for the duration of the investigation. This resulted in inconsistent iteration of the process and lack of ownership in validating and learning as teams dissolved before long-term results could be identified. Objects and tools that did exist were poorly coordinated. Standard work, process maps and documented procedures did not clearly define dependencies and differences. These documents were written at a general level to allow the flexibility to customize the process to local requirements. Documents that were more detailed became outdated quickly as organizational or procedural changes failed to get updated.

Boundary Effects and Barriers: Several barriers existed that effected the transformation of knowledge. Listed below is a highlight of the more critical problems identified:

- Cultural barriers due to geographic isolation resulted in customized operations and localized knowledge. The differences resulting from these actions have been used as an excuse not to coordinate knowledge transfer and sharing with other departments.
- Misrecognition- Quality Engineering and Failure Analysis dept. perceived boundary differently. Quality Engineering was more customer sensitive while the Failure Analysis dept. was more technically oriented. This resulted in different solution spaces that needed to be negotiated. Also, as mentioned above the cultural differences of business units have resulted in perceiving the boundary different. Organizational responsibilities were similar (dependent) but the roles and responsibilities were different. The semantic boundary was not sufficiently defined to identify and understand these differences resulting in misrecognition of the boundary. The results were tasks not being accomplished and full closure not being achieved.
- The lack of tools required the most senior, experienced people to get involved in performing trade-offs and evaluating different scenarios. With no formal review team to assess the solutions being generated it was left to the individuals involved. The probability of assembling a team of senior members during an investigation was remote and usually only occurred during major investigations.
- Path Dependency tends to generate old solutions to new problems. As novel technology and problems arise the process must promote the evaluation of new, novel solutions. The lack of tools made this difficult. Compounding the problem was the lack of validation being done by the team/individuals implementing the solutions. By not requiring the team that generated the solution to validate the results it separates outcomes from actions. This eliminates a critical learning process in identifying the competency trap. Many solutions work in the

short-term only to fail long-term. If the team/individuals did not validate the long-term results of the solution they tended to leave with the impression that their solutions were sufficient therefore propagating the competency trap.

4.4.3 Dynamic perspective

One of the main goals of the quality control process was the elimination of all recurring component defects. The metrics chosen to validate the success of achieving this goal was not representative of the effectiveness of eliminating recurring failures. The metric primarily used to monitor quality was defects per million parts produced. No component will have zero defects due to random failures always being present in the industry. This results in the metric measuring recurring failures (abnormal) and random failures (normal). Because the percentage of normal, random failures was high compared to recurring failures the metric did not represent how effective the process was at eliminating recurring failures. Validation also did not directly tie the long-term results back to the team or individual that generated the solution. This does not allow the team/individuals generating the solutions to validate the expected results or to learn from the reasons for the failure of the solution.

Iteration on an operational level was high due to the reliance on quality control to resolve component issues. Due to the number of functional groups and individuals involved, even with a high level of iteration, teams still struggled with inconsistent membership and levels of experience. Iteration as a vehicle to develop experience was also slower to materialize in quality control because no two investigations were coordinated the same and the lack of a standard procedure or validation or results made it difficult to assess the success from investigation to investigation. Iteration from an evolutionary process standpoint (incorporating process improvements) is similar to the boundaries described previously. There were no standard procedures or methods to consistently iterate around or even to require iterations to occur. This resulted in ad-hoc operation where iteration for the specific purpose of improving boundary objects and procedures was usually preceded by a negative event that led management to establish a review team.

4.4.4 Knowledge representation

Knowledge representation during the quality control process suffered the same generic problems as previously outlined during failure analysis and new technology insertion. Repositories were numerous but with poor access, localized data and insufficient information to recreate the circumstances of the initiating event. Within the quality control process this lack of knowledge representation was even more problematic. When investigations were completed the knowledge was not properly captured. The result was an inability to retrieve the data and reconstruct the original event that occurred. When component failures did re-occur the first effort undertaken was trying to recover and recreate the conditions and reasons for actions from the original investigation. Without complete knowledge the actions taken could not be effectively analyzed and lessons learned could not be sufficiently defined and incorporated for future reference.

Another problem with the knowledge representation phase of the quality control process was the lack of value attached to data. This did not allow the focus of resources to occur on those knowledge sources with the highest value. Even more concerning was missed opportunities not identified by evaluating new, novel uses for knowledge and the value it might represent. As an example, Hamilton Sundstrand was not capturing the data on different suppliers and their performance in a manner that allowed them to understand the reliability of the supplier. They stored information in individual databases for failures but did not link these databases, i.e. the purchasing dept. could not access these databases directly. The databases also did not include proactive data such as on-time shipments or quantity of passing components shipped. To evaluate a supplier you need to know how many problems they created (defects, late shipments, cost variations etc.) as well as how many acceptable components they had supplied. This would provide the knowledge required to evaluate the overall cost efficiency of a supplier instead of basing the decisions on the individual cost of the components alone. This resulted in the potential selection of suppliers with higher overall cost being selected because component price was the main factor while knowledge representing performance costs was not available and therefore not included in the solution process.

4.4.5 Discussion

Much of the responsibility for resolving new sources of novelty ended up being incorporated into the boundary developed around the quality control process. The lack of a strong semantic or pragmatic boundary coupled with ineffective validation resulted in the degradation of the boundary that led to long-term quality problems as new sources of novelty were introduced. The lack of an iterative process to promote improvement and process evolution resulted in a static process that could not prevent or slow the degradation of the boundary. This degradation was not identified until it severely impacted other metrics and goals outside the boundary that were being more closely monitored, i.e. customer satisfaction decreasing. As a result, a 'Red team' was established to iterate the process to resolve problems created by the new sources of novelty. The development process used to evolve the quality control process resulted in an up to date procedure that remained static and ineffective in dealing with future new sources of novelty. This created the original conditions seen that lead to the degradation over time of the boundary initially.

Chapter 5.0 Discussion of Results

In the previous section the framework established in chapter three was used to analyze several boundaries that were critical to the successful implementation of commercial plastic components. Problems and difficulties with those boundaries were analyzed and the effects these problems had on the success of the initiative were evaluated. Within this chapter we will look at several of the common themes that were identified during the research of the new technology insertion and the analysis performed at the critical boundaries. The themes provide further analysis and insight into some of the problems that occurred across several boundaries. These themes can be considered general insights into boundary difficulties and not specific to just those boundaries that were analyzed within the commercial plastic component initiative.

5.1 Theme I. Boundary Awareness

Boundary awareness is a reflection of the ability of the individuals or groups to recognize and understand the complexity and difficulties in exchanging information, transferring knowledge and creating knew, novel knowledge and solutions. As the complexity of a boundary is increased the effect it has on the transfer of knowledge becomes more problematic. As part of the discussion on boundary awareness I looked at how novelty is addressed to minimize or reduce complexity and then looked at the consequences the added complexity has on the awareness and control of the boundary.

5.1.1 Novelty (Internal and External)

As outlined in section 3.6.1, novelty can be characterized by its source, magnitude, impact and timing. Novelty will increase boundary complexity until it has been identified, understood and reacted to. As the process evolves to acclimatize the novelty it ceases to be novel and instead becomes absorbed as part of the new boundary process. This may result in the boundary becoming more complicated, due to changes incorporated, but the level of complexity will be reduced. The reduced complexity is a result of the individuals who function at the boundary being aware of the novelty, having learned from it and having adapted to it's impact. When commercial plastic components were introduced the magnitude of the novelty was sizable. This resulted in significant impacts to many of the processes and boundaries established as well as the creation of new boundaries. When the novelty is part of a new initiative or results in a significant, visible impact it is clearly planned for and adapted to. This was clear in all the boundaries that were evaluated. The implementation program for commercial plastic components was very detailed and well staffed. It wasn't until several years later that the novelty introduced through technological advancements began to cause problems. This novelty could be characterized as lower in magnitude and impact but faster in its timing characteristic. The commercial plastic integrated circuit industry was growing at a rapid pace. Moore's law accurately predicted that the storage density of memory devices would double approximately every 18 months[13]. This has been a leading example of the rapid pace of the technological advancements. Although the magnitude and impact of each change was not major, the volume of changes over an extended period of time culminated in problems of larger and larger magnitude. Many of the technological advancements were related to or dependent on previous technological advancements.

[13] Gordon Moore, who co-founded Intel, roughly predicted in 1964 that the amount of information capable of being stored per unit size of silicon will double every 18 months.

Charlie Fine, in his book on industrial competition, described the rate at which different industries evolved as 'Clockspeed'[14]. Larger industries, such as the automotive and aerospace industry had very slow clockspeeds taking decades to evolve. At the other end of the spectrum were the personal computer manufacturers and Internet companies who had very fast clockspeeds measured in days and months. The commercial plastic component manufacturers could be characterized as an industry with a clockspeed measured in months. Once the new technology initiative was implemented the clockspeed of the industry responsible for the technology was never addressed. By identifying the clockspeed of the driving industry that is a key factor in your boundary you are identifying the rate of innovation and therefore the rate on novelty introduced into your system or process. This clockspeed becomes an input to determine the rate of how often the knowledge transformation cycle is repeated, and what kind of resources will be required to manage the boundary.

In addition to the clockspeed of the commercial plastic component industry, another factor shaping the boundary over time was Hamilton Sundstrand's organizational clockspeed. Organizational clockspeed would introduce novelty through changing the functional groups, people and requirements of the boundary. As outlined earlier, the merger, acquisitions and volatility of workforce levels resulted in a very rapid organizational clockspeed. This too was not factored in when determining the rate of iteration the process needed to sustain to remain efficient.

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[14] Fine, C. 1998. Clockspeed: Winning Industry Control in the Age of Temporary Advantage.

5.1.2 Manpower

Manpower, or more accurately the lack of manpower, was an issue brought up by each employee as well as manager who was involved in my research on boundary analysis. The research performed was not sufficient to determine the appropriate manpower required. The lack of manpower is a cause for activities not to be accomplished but was being overused as a reason for inefficiently performing the remaining task. Tasks must be prioritized and planned for to properly focus and perform those tasks that have a high priority. This was not being done and the result was many individuals who were overwhelmed. Instead of trying to do a few things well they were accomplishing doing many things poorly. When possible, ineffective boundary operation caused by lack of manpower was identified and treated separately from that caused by inefficient processes. This was not always an easy task due to the dependency between manpower and efficiency.

Three factors that attributed to the manpower issues were, (1) low estimate of manpower requirements during the transition from development/implementation phase to operational phase, (2) organizational clockspeed was not defined to allow review of manpower requirements, (3) industry clockspeed was not defined to determine impact novelty has on boundary complexity and manpower requirements. Items two and three were addressed in the previous section on novelty while the following addresses item one. Manpower estimates are a difficult task and are typically underestimated during the development and planning stage of most initiatives. During the development and planning stage the visibility, resources and priority the project received were very high. Although the direct, full-time staff was well understood, and therefore accurately estimated when future planning was performed, it was the indirect people behind the scenes that were not clearly estimated but who played a critical role in the success of the initiative. It was this unaccounted for element of manpower that helped to overcome the inefficiencies in the system by 'expediting' through them. The resources and priority were also very high resulting in execution times that were much faster than would be experienced in the normal system. The result is a process that runs effectively, although somewhat inefficiently, utilizing many unaccounted for resources. Once the implementation is complete and the process is required to stand alone it immediately faces manpower issues. Over time, as additional novelty is introduced, the situation continues to intensify. In the absence of any iterative process that identifies or adapts to the new conditions the boundary continues to degrade until visible problems force the issue to be addressed.

5.1.3 Requisite Variety (also referred to as absorptive capacity)

The law of requisite variety "states that the variety within a system must be at least as great as the environmental variety against which it is attempting to regulate itself. Put more succinctly, only variety can regulate variety."[15] The high rate of novelty being introduced by organizational change and technological advancements was increasing the variety that existed within the boundary. As described in section 2.3, when commercial plastic components were being evaluated an aggressive plan was implemented to insure that the proper level of training (learning) was developed resulting in informed and knowledgeable decisions being made concerning the use of commercial plastic components. This is what Buckley would describe as developing the requisite variety. Over time the clockspeed of the commercial plastic component industry resulted in introducing substantial new variety into the processes and boundaries involved. The same level of variety was not developed internal to Hamilton Sundstrand.

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[15] Buckley, W. 1967. **Sociology and Modern Systems Theory.**

Eventually the disparity became so large that boundary efficiencies began to suffer. Time and resources were being wasted because the impacts of decisions, due to the new sources of novelty in the system, were not clearly understood. Effective new solutions could not be developed because the dependencies and differences brought on by this novelty were not clearly identified. As a result of the increasing novelty and reliance on old knowledge and syntax competency traps developed.

Due to the competency traps, problems created by the new source of novelty were allowed to reoccur. When visibility of a problem created was high enough it forced the issue of developing the appropriate requisite variety to recognize and resolve the novelty. This was effective at resolving the recurring issue but was done reactively and only in those cases where significant visibility was applied to the problem. Most boundaries reviewed did not have any formalized plan to proactively develop the requisite variety necessary to handle the novelty before it escalated to a significant problem. The only existence of any process to develop requisite variety was informally through individuals reading trade journals or doing personal research to assist in resolving issues that may be of particular interest to them.

5.1.4 Syntactic and Semantic Boundaries

Commercial plastic components are highly technical and their application in Hamilton Sundstrand products was technically challenging. The high level and variety of technical capabilities required led to some areas of highly specialized functions. Specialization and novelty are two characteristics that increase the complexity of a boundary. As I reviewed the syntactic and semantic boundary features it became clear that the complexity was being handled by focusing on differences instead of dependencies. Boundary users identified the difference that the novelty or complexity created and then used this difference as a justification not to include the novelty or complexity as part of the boundary. Users were treating the novelty or complexity locally or not at all. The result was local management of a global process. Each functional group was making decisions individually instead of as a team. Processes were locally optimized but the global system was inefficient. The outcome was that knowledge was not being shared or transferred. New solutions were not being developed or, if they were did not address or account for all the dependencies and differences that existed and were never identified.

5.2 Theme II. Path Dependency (pragmatic)

The negative effect of path dependency is the condition of using old knowledge and syntax to resolve new problems or novelty. In this day an age of re-use of processes and designs as a means of reducing cost and development time it is easy to get caught in a competency trap. Path dependency was a common occurrence in the boundaries reviewed. The outcome was inefficient operation or ineffective solutions. The primary problem was that the old processes were sufficient enough to get the job done (inefficiently) or were effective enough to 'band-aid'[16] the new problem. This resulted in problems recurring or the inefficient use of manpower and resources. As part of the discussion on path dependency I explore several common observations across the boundaries analyzed that made them susceptible to the competency trap that developed due to path dependency.

[16] Band-aid was a reference to quick solutions that did not address root cause and therefore were ineffective over the long-term.

5.2.1 Overemphasis on dependence at expense of difference

During the previous section on boundary awareness we saw that overemphasis on difference at the expense of dependence was problematic for syntactical and semantic boundaries. The result was a lack of knowledge transfer. Reversing the conditions and over-emphasizing the dependence at the expense of difference was a common cause for falling into the competency trap at many boundaries. When the new technology was implemented a review of the old processes was done to determine if they would still be effective under the new conditions. The dependencies were clearly identified and easily understood. The differences, because they were novel, were not as easily understood. Obvious differences were addressed and resolved. More subtle differences were overlooked or left to be 'ironed-out' later. Part of the problem lied in the initial desire to want to make progress. By focusing in on the dependencies it opened the door for re-use of old processes. This would help to reduce cost and development time by not having to 're-invent' the wheel. Focusing in on differences would have resulted in delayed short-term results but more robust processes. As is typical with most programs, time runs out during the development phase and the implementation phase is to short or constrained to properly identify all sources of difference. The outcome was relying on path dependency to expedite process development; the result was falling into a competency trap that continued to deteriorate over time. The old methods and syntax could only specify the old dependencies and differences, so what transferred seemed acceptable at the time. Representing novelty you have to be able to represent new dependencies and differences and their relationship with the old ones.

The initial path dependencies created during the implementation phase of the new technology were not severe and did not result in major problems. Unfortunately, as novelty was introduced into the system and not resolved, new dependencies and differences were added and the old processes continued to degrade over time. Compounding the problem was the lack of requisite variety to clearly identify the differences that existed and were not being addressed by the old processes. This resulted in looking towards solutions that were more costly and ineffective but whose differences and dependencies were more clearly understood. An example of this condition would be Hamilton Sundstrand adding in inspection processes to evaluate the quality of a manufacturer's components instead of developing a more robust supplier and component qualification procedure to identify the problems before the manufacturer is selected.

5.2.2 Requisite Variety

As mentioned in the previous section requisite variety is critical in recognizing the path dependency. In other words, you can't recognize what you don't know. A common characteristic in those boundaries that exhibited path dependency was the lack of requisite variety. There were several potential reasons for not developing the necessary requisite variety to address the novelty being introduced. Lack of manpower, time and budget were some of the consistent reasons but one reason stood out above the rest, responsibility. Whose responsibility was it to develop the proper training? Many people felt that it was the responsibility of the commercial plastic component manufacturers to police their own quality problems and to institute appropriate action. It was our responsibility, Hamilton Sundstrand, to identify the failures and hand off the problem to the manufacturer to do the rest. This unfortunately was a competency trap in and of itself. In the industry of military components, that's how the majority of manufacturers operated. Quality was their primary concern. This and component cost are what drove their sales. In the commercial plastic component industry the major business driver became cost with quality as an important but secondary parameter. This seemed to be only a minor difference and therefore allowed Hamilton Sundstrand to use the old process. Using the old process eliminated the worry about developing the necessary but costly experience to be able to understand the novelty being introduced.

Originally the change to commercial plastic component manufacturers seemed to be only a minor difference compared to the military manufacturers. This difference turned out to be very significant with the more problematic suppliers, even though they represented only a small proportion of the overall supplier base. Because of the emphasis of commercial components on cost, suppliers were now more constrained themselves in terms of the budget and resources they could allocate to resolve smaller customer issues[17]. This eliminated a resource of requisite variety that still has yet to be filled. This is not indicative of all Hamilton Sundstrand suppliers and therefore is problematic. A majority of component manufacturers would still thoroughly support investigations and provide the level of requisite variety required. This justified the continued use of the old processes that relied on the suppliers for their solutions to novel component issues. Unfortunately, over time the number of suppliers who couldn't resolve customer issues, and the competency trap that lead to ineffective solutions, resulted in additional recurring problems. Eventually the number of recurring problems increased to the point where they overwhelmed the system and the appropriate actions were taken.

5.2.3 The right people, the right tools and the right attitude

Once or twice a year a major investigation would be conducted due to a significant quality problem being experienced. Within this environment there were sufficient resources and

[17] Hamilton Sundstrand typically represented less than 1% of a suppliers business. This resulted in resources and priorities going to the suppliers' larger customers.

the development of requisite variety to overcome path dependency. Then why was it that boundary users still fell into the competency trap? The main reasons that I concluded from my observations of several component investigations was that once you have fallen into the trap it is not easy to get out of, even when the resources are available. The right people, tools and attitude still must come together to identify the trap, acknowledge its impact and then implement a solution. The right person indicates that the functional group specialists that are the most familiar with the dependencies and differences of the group are assigned. Too many times the less senior people who were not working critical tasks were assigned to the long-term investigations. The justification was that they would still have access to the senior specialists to resolve issues. This unfortunately resulted in delays and unrecognized solution opportunities. The right tools indicated that the tools necessary to identify consequences and evaluate trade-offs existed to provide new insights and promote new solutions. These tools did not exist but the use of integrated engineering teams to explore and evaluate trade-offs accomplished the same objective. Having said this the right people and sufficient tools were usually available during the major investigations; it was the attitude of the boundary users that was the most limiting. The attitude of the people involved must be 'out of the box thinking'. They needed to feel comfortable in breaking from the path dependency and exploring new ideas. Unfortunately the culture, management and teams all appear to stay within the old process trying to add new 'twists' to old solutions that didn't work to begin with. This seemed to afford a level of comfort by dealing with a known, established process and level of risk. It also was the process that people were used to and forced to revert to the remainder of the year when they were faced with the normal conditions of insufficient resources to resolve lower priority issues. An indication of this attitude is communicated in a common saying during investigations when new manufacturers were being considered to replace existing manufacturers that were experiencing on-going quality concerns: "Better the Devil you know then the Devil you don't know". Although this does not speak directly to path dependency it does indicate the level of risk that people were willing to take to explore new, novel solutions.

5.2.4 Selection of global metrics vs. local metrics

The first three observations addressed the issues of path dependency at the boundary level. Selection of local metrics vs. global metrics illustrates an observation that a factor of path dependency is not recognizing the inefficient results being obtained from solutions generated at the pragmatic boundary. Many times the individuals or teams that generated the solutions did not perform long-term validation of the results. This was due to many teams being dissolved before sufficient time could pass to allow accurate validation. This led to teams that concluded from short-term results the effectiveness of long-term solutions. Realizations of the effectiveness of solutions could take several months or more before sufficient validation and confidence could be generated. This resulted in teams and individuals not being able to learn from their mistakes or to understand the consequences of ineffective solutions generated. Another result of poor metric selection was the syndrome of 'Paying for A while hoping for B'[18]. An example of this condition is the pragmatic boundary existing between Hamilton Sundstrand's quality department and failure analysis department. Coordination between these two departments is driven by their dependence on each other to resolve component manufacturing defects. The difference between the two is that quality is responsible for customer satisfaction and failure analysis is responsible for quickly analyzing the technical cause of the failure.

[18] Reference to article by Steven Kerr, '*On the Folly of Rewarding A, While Hoping for B*'

Together the two departments are responsible for insuring that failures are properly identified, resolved and don't impact the customer. Locally the failure analysis department was measuring their speed to analysis and ability to determine the failure cause. Quality was monitoring number of defects being generated. Each department's metrics showed improvements in year over year measurements from 1999-2001. What the metrics didn't show was how effective the quality department and failure analysis department was in coordinating knowledge transformation to identify true root cause and implement corrective action to insure the failure did not repeat. Because the local metrics were influenced by many factors they were not good indicators of how effective the boundary between the two departments was being handled. In this same time frame of 1999-2001, although not measured, the recurrence of failures was increasing. This increase led to more latent failure modes that increased the probability of failures being detected later in the process or at the customer. In this example we were incentivizing the functional departments to achieve their local goals while hoping that it would result in the establishment of an efficient boundary. The metrics used did not represent the boundary and therefore did not reflect the inefficiencies within the boundary that might have foretold the problem of falling into the competency trap. The metrics were measuring the transfer and translation of knowledge hoping that it would result in the transformation of knowledge into effective solutions.

5.3 Theme III. Creating a Dynamic process (change, validation, iteration)

Creating a dynamic process reflects the ability of the process to accommodate external change and, more importantly, to promote internal process change to adapt to that changing environment. Throughout the research it was evident from review of process control documents and procedures that very little had changed in the way that boundaries were being coordinated over the course of several years. During this same time period numerous organizational changes and technological advancements were occurring. As part of the discussion on a dynamic process I will look at several common observations across the boundaries analyzed that resulted in the development of a static process that degraded over time due to it's inability to adapt to novelty.

5.3.1 Novelty not planned for or embraced

No process can remain rigidly constant. Each process is comprised of an element of stable activities and inputs as well as a dynamic element consisting of novel inputs or organizational change. Both elements need to be addressed within the development of the process. The boundary processes reviewed were considered by their users to be stable, robust procedures that were slightly outdated but still very effective. The indication that the procedures were outdated, even if only slightly, came from people recognizing that the process had remained stable during periods of novelty that required the process to adapt. Very few processes reviewed had formally built in a step or section that actively promoted change or the evaluation of the need for change. Every process included steps on how to formally incorporate change and most people alluded to this when asked about change. This was passively supporting change. It formalized how to change the process once the change had already been identified. What was missing was a formal procedure that encouraged people to understand new sources of novelty introduced into the system and to evaluate changing the process to adapt to this novelty. Also missing was the encouragement of creating change as a means of evolution and improvement.

The cycle that was most evident during review of the processes used to control boundaries is illustrated next. A process would be created and then introduced into the system. People realized that the new process would require change and planned for it during the implementation stage. After the initial problems were worked out the process was considered robust. Unfortunately this also seemed to be viewed by the users as the process being stable. Over time novelty would eventually cause the efficiency to erode until the cost to support the inefficiencies became too burdensome or the problems created to severe. The situation would then receive enough visibility to warrant action. Resources would be applied and a 'RED Team' established to correct the problems. The process would be re-engineered. Re-engineering would involve performing a gap analysis between the process being used and the environment within which it would operate. The team would then recommend changes and typically implement those changes. This statically closed the gap within the present environment but did not look forward to the future. The re-engineering addressed the size of the gap that developed but did not look at why the gap developed, why it wasn't detected and how to keep it from developing in the future. This perpetuated a cycle where the boundary process would be developed that didn't incorporate novelty, would erode over time, and then be fixed with the same inability to handle novelty thus starting the cycle all over again.

5.3.2 Fear that creativity and learning eliminates consistency and efficiency

Part of the problem observed with creating a process that has elements of stability and novelty was finding a balance that would make all users feel comfortable. The stable element of the process would benefit from consistency by allowing repetitive functioning to increase experience and efficiency of operation. The novelty within the system would benefit from an environment that encouraged change and promoted evolution of the process to adapt to a dynamic environment. If done properly the system would have elements of both that would keep the system in tension but would not result in conflict.

The specialists within a functional group felt that many of the processes developed were to stable and did not promote novelty within the system. Unfortunately they were in the minority with the majority of boundary users being generalists who favored consistency. This consistency they felt would promote a more efficient syntactic/semantic boundary. The specialists were fearful that any form of consistency, such as standard procedures, would stifle their creativity and use of novelty. The generalists and management on the other hand, felt that not standardizing the process would lead to excessive variation and cost. Both sides could not come to an agreement on how to develop a process that could incorporate both. The generalists usually won the battle and process stability was incorporated. The lack of an acceptable process lead to the specialists becoming more internally focused (localized) resulting in a reduction in the amount of participation and knowledge being transferred across the boundary.

5.3.3 More emphasis is put on complex "robust" processes instead of flexibility

As mentioned in the previous two sections, Hamilton Sundstrand did not encourage or promote novelty within the development of their processes. This did not mean that they entirely disregarded novelty in the system or the need to accommodate it. In the boundaries observed and the processes reviewed what emerged was a philosophy of addressing novelty by making the process more complex. The additional complexity was seen as a more 'robust' process that would anticipate novelty that would be introduced. This resulted in processes being large, complex and difficult to maintain. Overtime what made these processes difficult to utilize was the introduction of novelty not anticipated and, more importantly, was the turnover in personnel. The processes were more effective when the people who had a hand in their development were the users. These were the people that understood the complexity and the justifications behind it.

As workforce volatility increased many of the original developers moved on to new positions. The people that filled their positions were not as experienced and were not aware of the reasons behind the complexity of the processes. They struggled to understand the process and to make it work efficiently.

What was missing in almost all processes reviewed was a designed clockspeed of the process based on the clockspeed of the technical and organizational novelty being introduced. The processes developed by Hamilton Sundstrand were large and complex when they should have been designing smaller, more flexible procedures that relied on iteration to address novelty. Iteration of the process would promote rapid, small change as a means of evolving (adapting to the novelty). The result was processes that were sluggish in responding to novelty and the degrading of many boundaries whose rate of degradation was based in part by the clockspeed of the novelty being introduced.

5.3.4 Latency may be increased when system does not adapt to new problems.

Latency, or latent defect, is a term used in the electronics industry to describe problems that remain dormant for a period of time before activating and resulting in a failure. Latent defects are a concern because the longer it takes to detect a defect the more problematic and expensive it is to correct that problem. During my research I came upon a few instances where the lack of iteration and adaptation to novelty increased the latency of a problem. Although not a strong observation it is one worth noting. Part of the problem observed can also be attributed to path dependency. This effect can be described more effectively through an example.

Top of die delamination (TODD) is an issue that the manufacturers of commercial plastic components must monitor. It is a condition that weakens the plastic component package and in some cases may result in a latent failure of the device. Hamilton Sundstrand experienced this failure condition on a lot date code (LDC)[19] of parts. The parts were immediately identified and the entire LDC removed off the manufacturing floor at Hamilton Sundstrand. The investigation never identified root cause and concluded with the component manufacturer optimizing several parameters measured during the manufacturing of the components. Approximately 18 months later the same manufacturer exhibited the same type of failure on a different LDC. The same actions were taken to remove the parts from the floor. This time the corrective action involved implementing screening to improve detection of this problem. It again does not address the root cause of the failure. By the lack of an iterative process they were failing to learn from their mistakes. They did not apply new knowledge to help solve the more difficult problems. The system remained static and relied on old knowledge and processes to fix problematic novelty. By implementing a screen they did not address the root cause of the failure. The screening will help to detect more failures but it can't be considered 100% effective. This results in some parts passing the screen only to fail at even later stages of manufacturing where the costs will be increased. From a cost standpoint this may be more effective if the number of latent defects is small compared to the number of defects detected at the new screening process. What this doesn't evaluate is whether there may be a better solution that could have built on knowledge learned from previous iterations that might have suggested a whole new approach. An approach that doesn't increase the latency of the failures and may not require the additional cost of screening.

[19] Lot Date code is part marking that identifies when a part was manufactured.

5.4 Theme IV. Knowledge representation (storage, retrieval, value)

Knowledge representation reflects the ability to cost effectively store information, retrieve it and the transform that information back into value added knowledge. This is an extremely difficult process for any large company and Hamilton Sundstrand is no exception. It is clear from the research conducted that knowledge representation is a low priority. During observations of several investigations the issue of knowledge storage came up. Two of the investigations were on components that had failed only 18-24 months earlier and had gone through a similar investigative process. Information from these previous investigations was retrieved to gain insight and to review lessons learned. From the information retrieved it was clear that only a small portion of the data had been captured, even though each individual department had stored a significant amount of data. The majority of the data stored was redundant and of limited value. Even under this auspicious beginning, when the investigation concluded very little effort or thought was put into storing the new knowledge more efficiently this time. As part of the discussion on knowledge representation I will look at several common observations across the boundaries analyzed that resulted in the limited value and cost effectiveness of the knowledge representation process.

5.4.1 Too many local 'localized' databases.

A consistent observation across all the boundaries reviewed was the lack of a common, shared repository. Where a common repository had been established all boundary users were clearly not utilizing it. A review of the data in central, shared repositories showed that usage was limited and not equally distributed amongst all boundary users. The majority of entries would typically come from a single individual or group. Each functional group or user was storing most of the knowledge that was being generated locally. Storage of the data was done utilizing many different storage mediums. Shared networks, personal computers, paper files and personal experience were the more common forms. Access to these databases was protected and difficult to get. Compounding the problem was that each local storage repository was 'localized' to efficiently store data important to and generated by the controlling functional group. During many analyses where novel solutions were being encouraged it was clear that previous knowledge would have provided valuable insight to recurring problems or lessons learned. The functional groups involved would attempt to recombine their data to re-create the knowledge generated during previous incidents. The information retrieved indicated a high level of redundancy and a significant amount of boundary data that was missing. Boundary data involves the clarification of dependencies, differences and the negotiation of trade-offs. The knowledge re-created typically did not provide the necessary insights as to why certain decisions were made or the full extent of data available when making the decisions. The result was a significant of time, effort and cost put into the establishment of multiple repositories that did not provide back a significant amount of value or knowledge.

5.4.2 Tacit knowledge is seen as 'job security'

One of the most prevalent forms of knowledge storage was the tacit knowledge of the individuals who participated in the generation of the knowledge. Tacit knowledge is the experience and memories of individuals. This type of storage can be very effective but retrieval can be limited and problematic. One of the barriers to transforming tacit knowledge into explicit knowledge that can be shared is a perception that individual knowledge equates to 'job security'. The reasoning goes that if nobody knows how to do your job or has your knowledge then they will need you. This limits the amount of information and knowledge that is available for other groups to benefit and learn from. It also hinders the ability of a boundary to clearly identify dependencies and differences. As an example we can look at an effort to establish standard work procedures within each functional group. Standard work is a boundary tool that can be shared to communicate dependencies and differences. Many people were reluctant to support the creation (transformation of tacit knowledge to explicit) and use of standard work. Part of the problem was covered above when the issue of using consistent processes was seen as an impediment to creativity and novelty. The additional problem occurs because people were afraid during periods of downsizing that if they detailed how they perform their job (which includes boundary information) that they may be let go in lieu of hiring less experienced, cheaper labor or combining their job with another person who performs similar activities. Although management viewed standard work as an enabler, it was seen by some employees as a potential threat to their continued employment. As a note, there was no evidence or historical data to support that management, to allow the layoff or replacement of employees, used standard work. Also, it may seem that this fear would be contained within those employees who are the substandard performers within the group. This was not the case. The fear of losing job security through standard work did impact the specialists within a function or department more than employees with general job descriptions but the feeling was not segmented clearly to performance, age or other factors.

5.4.3 Value is not attached to knowledge

Although a significant amount of data was stored during the processes observed it was not clear what the level of re-use of that data was, or the value gained from its re-use. Some data storage was due to contractual requirements but this was small compared to the total amount of data being stored. Information was required and re-used on a regular basis. Other information was desired but couldn't be located, or couldn't be properly retrieved and reconstructed to provide the knowledge desired. Finally, some data was never stored and therefore lost forever. What was clear across all boundaries was that there was significant activity surrounding the storage, retrieval and transformation of knowledge. What was not clear was the cost incurred for storing and maintaining this data, the level of re-use or the value of the knowledge that was retrieved. Not all knowledge is good and not all information stored is valued. Incomplete knowledge was seen to lead to lessons learned having to be relived. As another example of knowledge not providing a benefit to all users lets look at the boundary between Hamilton Sundstrand's quality department and the commercial plastic component manufacturers. During investigation of a component defect with the manufacturer Hamilton Sundstrand is reluctant to share knowledge about the quantity of parts purchased, the number of failures or the environmental conditions under which the part failed unless absolutely necessary. The reason behind this evasiveness is the reluctance of manufacturers to spend significant resources on customers who don't deal in large quantities, who may have only experienced a few failures or may use the part outside specified environmental ranges.

Hamilton Sundstrand does not sufficiently understand or attempt to quantify the value of the information being stored. No direct analysis of the value was performed during my research but an estimate would be that only a small fraction of the cost of storage is being recovered by re-use of the information. Compounding the reduced value of information stored is the ability to transform the data into value added knowledge. As mentioned in the section above the data is stored locally and contains information identified as valuable to the controlling group. This limits the value to other groups and reduces the level of re-use.

5.4.4 Knowledge storage not planned for.

Knowledge collection, storage or review was never observed as a specific process step in any of the processes or activities observed. Some of the time responsibility was assigned to a specific group or person to generate a report to capture knowledge developed. The content was not specified nor was the activity shared. This resulted in the data being stored locally with information perceived by the author as being valuable. The majority of the time the activity resulting in the generation of knowledge would end and the time was not allocated to insure that all users involved coordinated the composition and storage of that knowledge. Participants would move on to their next assignments and would not revisit the information documented until it was required to meet a specific need. As a result, the information generated during the activity became the only data stored. This resulted in a high degree of redundancy of information as well as a significant amount of data that did not have the requisite supporting information to understand the syntax and semantics required to recreate the knowledge intended. It is ironic that most of the major investigations or process activities involved an initial step of reviewing past knowledge sources both internal and external. Many times there was visible frustration over the lack of attention to capturing previous knowledge created. Unfortunately by the end of the investigation the sense of frustration was forgotten and the cycle of ineffective knowledge storage was repeated.

Chapter 6.0 Conclusion

In the previous sections we developed a framework for the analysis of boundary activity and then used that framework to analyze several key boundaries created by the new technology implementation of commercial plastic components. This section will address recommendations based on the previous analysis. The recommendations will cover the major, underlying root cause issues and propose actions to minimize/eliminate the problems identified. Concluding this section will be recommendations for future research to address concerns with the implementation of a new technology not covered within the context of this paper.

6.1 Process Development Methodology

One of the issues that made it difficult to analyze the critical boundaries and the effectiveness of the processes developed to coordinate the transfer of knowledge across those boundaries was the lack of any structured process format. This resulted in a weak shared syntax, no method to explore dependencies and differences, and no opportunity to incorporate lessons learned. The first and what I would consider the most crucial recommendation is the creation of a consistent process development methodology. This consistency in application allows improvement from the incorporation of lessons learned and knowledge generated through iteration of the process methodology. Hamilton Sundstrand's process development methodology was random and ad hoc. This made it impossible to incorporate lessons learned and knowledge generated because of the amount of novelty (dependence and difference) in the system from iteration to iteration was high compared to the amount of consistency (stable dependency). Each process must contain elements of both consistency and novelty. Consistency allows efficiency through iteration. Novelty allows the process to create or adapt to new dependencies while minimizing the impact of differences. Creating too much novelty from process to process creates excessive differences that do not allow for the benefits of consistency. Variation introduced to resolve new sources of novelty (organizational or technological) may have been a requirement but most of the variation being introduced at Hamilton Sundstrand was a result of the ad hoc application of process development. New people and managers meant a new approach to process development with different results.

Boundary objects: The first boundary object required would be the generation of a ***standardized method for process development***. A standardized method would promote a shared language as well as allow individuals to learn about dependencies and differences. It would also provide an opportunity for process improvement through the generation of new knowledge from lessons learned. If a consistent process development methodology was created what might it look like and how would the framework developed in section three fit into this methodology? This topic is sufficient to warrant another thesis and is a follow-up recommendation. The following presents a high level ideology of the process development methodology that can be used as basis on which to promote discussion or perform future research. Looking at the processes used and how they were created there were four main steps in the development of each process.

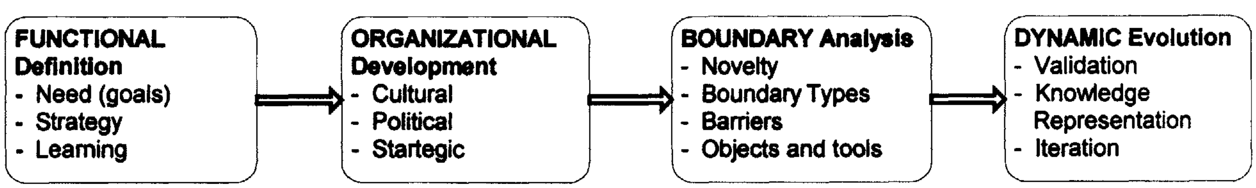

Figure 6.1-1 Process Development Methodology

The four main steps, as represented above in Figure 6.1-1 Process Development Methodology are functional definition, organizational development, boundary analysis and dynamic evolution. A brief description of the steps is provided below:

- Functional definition (Technical): Defined the needs, goals and requirements that the process was to fulfill. The step involved mostly technical analysis of the problem and solution space. This step begins to identify the knowledge required and what boundaries are created.
- Organizational development (3 lenses: cultural, political, strategic): Defined organizational control and responsibility. Looks at the organizational responsibilities of the boundaries.
- Boundary Analysis (novelty, '3-T': syntactic, semantic, pragmatic): Covered in section 3.5, looks at the actual functioning of the boundary.
- Dynamic evolution (Validation, Knowledge representation, Iteration): Covered in section 3.5, looks at the evolution of the boundary.

Within the development of a process the majority of the time and energy was spent at step one defining the technological requirements and complexity. With each corresponding step less and less resources and time were dedicated to the activity, almost no time was allocated to the activities of dynamic evolution. Because of this the processes developed were technically strong but very weak outside of this characteristic. This resulted in the processes degrading over time.

Additional objects that would be required for the standardized method to be effective are:

- The establishment of clearly defined ***goals*** to help focus the group and to provide constancy of purpose.
- The generation of ***process flow maps*** to communicate the roles, responsibilities, definitions and deliverables of the process being developed.
- The use of a consistent ***process to perform value engineering***. This will provide a shared syntax to communicate cost factors and provide an opportunity to negotiate the effect of new dependencies and differences.

6.2 Process Evolution- Iteration

"For an evolutionary process to take place there need to be variations (as by mutation, trial, etc.), stable aspects of the environment differentially selecting among such variations and a retention-propagation system rigidly holding on to the selected variations. The variation and the retention aspects are inherently at odds. Every new mutation represents a failure of reproduction of a prior selected form. Too high a mutation rate jeopardizes the preservation of already achieved adaptations." Donald T. Campbell (1965, pp. 306-7) Ethnocentric and other altruistic motives. In D. Levine (ed.), *Nebraska symposium on motivation*, 1965. Lincoln: University of Nebraska Press.

Campbell also suggests that for an evolutionary process to occur three components are required, (1) Variation, (2) selection and (3) retention. For a process to evolve it must introduce variation (novelty) into the system. This novelty may be in response to a change in outside stimulus (external sources of novelty) that must be adapted to or may be a series of improvements designed to provide greater efficiency in dealing with internal sources of novelty. With the introduction of variation the next critical step is selection. Selection is required to insure that only those sources of novelty introduced that resulted in improvements will be maintained. Finally, with the completion of selection retention must insure that the sources of novelty are retained and become part of the new system or process.

Process evolution is analogous to the process development methodology referred to in section 6.1. Variation is equivalent to novelty being introduced into the system. Selection is equivalent to the validation of the impact and results due to novelty. Retention is equivalent to knowledge representation in capturing the dependencies, differences and solutions created by the novelty. Iteration, which can be likened to evolution, will be covered in the following section.

Variation (novelty), selection (validation) and retention (knowledge representation) will be covered in sections 6.3 through 6.5.

Without a defined step for iteration in the process development methodology the result would be a static process that would degrade over time with the introduction of novelty. Iteration is the vehicle by which process evolution is stimulated. Iteration, as defined earlier, is comprised of two factions, (1.) the repetitive operation of a process whereby experience is gained through repeated execution and (2.) process analysis whereby effectiveness is increased through analysis of opportunities for improvement. Previously discussed was the concept of novelty and the clockspeed or rate of introduction of that novelty. In an evolutionary concept the novelty being introduced into the system represents the changing environment to which we must adapt to survive. Variation is the process of adapting to survive.

Boundary objects: The first object required is the ***process flow map*** generated as part of the process development methodology. The process flow map should clearly identify the inputs into the system and the roles and responsibility of the functional groups within the process. With the key process drivers identified analysis must be performed to determine the clockspeed of those drivers. The clockspeed will define the rate at which the key drivers (industries and organizations) evolve and therefor the rate at which they will generate new sources of novelty (new products, technologies, structures etc.). ***Definition of the clockspeed*** provides a boundary object to allow the negotiation of the rate of iteration. If the iteration rate is too low adaptation will be slow to respond, if the rate is too high then unnecessary costs will be incurred and excessive introduction of variation may result in previous improvements being lost. Therefore the rate of the iteration must be consistent with the clockspeed of the environment within which it must survive. Therefore process iteration must be actively planned for, must encourage the introduction of variation and must establish a rate that is sufficient to allow a response to new sources of novelty (technology, organization, business etc.).

6.3 Variation- Novelty

Novelty within a system can be very destructive if it is not identified and adapted into the system. When a process or boundary is being identified the users must look at all variation to identify potential new sources of novelty. The most effective way to accomplish this task it to follow history. As an example, one of the more problematic sources of novelty was technological advancement. By looking at the previous 5-10 years you could have developed a very accurate predictor of how fast the clockspeed was of the commercial plastic component industry. A simple research and analysis of industry literature or communication with the industry leaders would have confirmed that this data was indeed accurate as a predictor of the level of novelty going forward. The following are just some of the novelty that needs to be addressed when looking forward in the area of technological advancement:

- Ball Grid Arrays (BGA's), Flip chip technology, Die shrinkage (effect on wearout), higher memory densities (effect on reliability) and increased outsourcing by manufacturers.

The same approach is also used to determine the clockspeed for other major sources of novelty such as organizational. The following are just some of the novelty that needs to be addressed when looking forward in the area organizational changes:

- Workforce volatility, organizational restructuring, growth through acquisition and mergers, knowledge management, continued pressure to reduce costs, increased reliance on statistical process control, and increased demands on supplier certification (supplier quality) due to outsourcing and manufacturing problems.

When novelty is introduced one tendency is to identify the dependencies and then to accept the existing path (old process) if it has a significant overlap of dependencies associated with the new novelty. This results in the competency trap. Another tendency is to identify the differences and to accept dealing with the novelty locally (within your business unit, organization, functional group etc.). The tendency to deal with novelty locally is also a reflection of the lack of tools to properly learn dependencies and differences across boundaries and the associated problem of trying to negotiate solutions to these differences.

Boundary objects: As the novelty in the system is identified [content, source, clockspeed] it will allow the development of ***requisite variety planning*** to become more focused. Developing requisite variety can be costly and must be reconciled with current strategic philosophy. The needs and opportunities with which to create a knowledge development strategy (requisite variety) must be evaluated on the basis of strategic fit with areas that have been identified as providing long-term growth and competitive advantage. This is acknowledgement that not all requisite variety can be developed. The cost to develop vs. the benefits gained simply does not justify such a generic philosophy. By identifying novelty that may be introduced in the future and comparing this against strategic planning a picture of what variety can be developed internally and what should be partnered with or developed externally will begin to allow focusing of resources. Additional opportunities to explore would be benchmarking, industry experts and consortiums that may provide additional clarification of on the impact of novelty and lessons learned in developing a strategic position to handle such novelty. The previous opportunities represent sources of knowledge outside of the company. This presumes that all potential internal sources have already been identified and developed as a source of knowledge. One source that has been overlooked at Hamilton Sundstrand has been the information available through the use of statistical sampling and monitoring. Most sampling and testing of components are done reactively looking for a previously defined problem. Once the problem is resolved the testing is continued for a discrete time to insure quality is maintained. What is not done is the proactive monitoring of suppliers and components. This type of sampling would provide reliability data on components and suppliers that is almost impossible to recreate reactively. By identifying sources of data that might provide insight to problems and concerns before they occur you have identified internal sources of knowledge that are directly related to your processes and are controlled by your company. The price of this data would be free except for the cost to develop and maintain the monitoring plan.

Once the requisite variety has been developed, internally or externally, to deal with the novelty it is critical to identify and communicate the dependencies and differences that the novelty represents. Identifying the dependencies and differences will allow the boundary users to determine if the present knowledge transformation paths are sufficient to handle the new dependencies and difference or if new paths must be created. ***Process maps, standard procedures and specifications*** are examples of boundary objects that provide a method for individuals to learn about dependencies and differences. Process maps and standard procedures are effective methods to share dependencies but they must include the details as typically seen in specifications to insure that the differences are also clearly identified. With this understanding re-use of old processes, and therefore the potential to fall into the competency trap, can proactively evaluate all differences and dependencies to understand the new boundaries. Then we must understand how processing paths must change and by how much. The responsibility of re-use needs to insure that the process is efficient not only today but can easily grow over time to accommodate anticipated novelty.

The creation of ***models*** provides an object to explore and negotiate trade-offs. These models may be required to represent a process or technical product, both will be required. The creation of a model to represent the interactions and dependencies of a commercial plastic component is an example of a product model that would be a valuable tool to engineers trying to assess the impact of technological advancements. By understanding the dependencies and differences involved it would help the engineer to know which groups or processes might be affected. Models are usually only thought of to aid in the product development process and are rarely considered as tools to model novelty or to address the dynamics of an existing process. An example of a process model would be a system dynamics model of the purchasing system. Here the model would represent the different options available and how different purchasing decisions might impact the quality, cost and delays associated with receiving components from secondary suppliers or through brokerage houses. Both examples stated would provide immediate modeling of a system to evaluate trade-offs and negotiate decisions based on knowledge of the dependencies and differences experienced by all boundary players and not just those involved in the decision.

6.4 Selection- Validation

Validation is the act that allows us to evaluate the effectiveness of a process or to evaluate changes made to that process. Validation accomplishes the task of selection in an evolutionary process. If we are to know what variation is successful we must be able to measure the effect that it has on the system after it has been incorporated. As part of this analysis a comparison must be made to a differential in system output. To be able to do a comparison requires a knowledge of system performance prior to the variation introduced or, if validation is being performed for the first time, an estimated output performance. To perform validation the following aspects will be key to success:

- Boundary activities must be attached to a goal, perceived value, recipient(s), and creator(s). Before metrics can be chosen it must be clear what the intent, value and goal is of the process that is being monitored. Monitoring is not without cost and resource requirements. You can't measure everything nor is everything worth measuring. Chose only those processes that have been systematically prioritized.
- Estimate what the expected measurement outcome of the process will be, this will provide a test of your understanding of the system. To many times users will collect metric data first to define their understanding of the systems thereby losing an opportunity to learn from their misunderstandings.
- Select clear targets to be achieved.
- Consistent monitoring of key process elements. Many times users will only select monitoring after degradation of the process or boundary has occurred. The key processes or sub-processes must be identified and then monitored as part of process execution. This provides experience on process control and will allow the identification of degradation prior to critical problems resulting.
- Select representative metrics, avoid the trap of 'measuring for 'B' and hoping for 'A''. By properly selecting metrics the user will insure the critical process functions are being monitored.
- Select global metrics. Avoid the selection of key metrics that may be local to a group or function. These metrics have the tendency to be locally optimized to show improvements by

the responsible party but may not result in the desired impact for all process or boundary users.

Implementing an effective validation process will provide selection criteria to determine variation that should be retained and variation that has resulted in lower performance than desired or anticipated. This will also allow for resources to be focused into areas that require greater attention or will result in the greatest value return.

<u>Boundary Objects</u>: Before validation can begin the boundary objects of ***process flow maps*** and ***defined goals*** from the process development methodology must be received. Validation must clearly understand the process and the desired goal that it is validating. The implementation of an ***integrated engineering team*** needs to be established to oversee the selection, measurement and evaluation of metrics. The development of a team (assuming proper allocation of resources) provides a boundary object that can be flexible, responsive and experienced at implementing the validation process. The consistency of a team would help to develop the syntax and semantics required to understand the selection of metrics and the results achieved. A ***standard measuring method*** must then be created and accepted that defines how to measure the metrics that were selected. Finally, the results of the validation must be clearly and consistently communicated across the boundary and linked to the dependencies and differences that are driving the results to provide learning opportunities to all boundary users. To accomplish the communication and interpretation of results a ***standard form or chart***, such as a ***balanced scorecard***, will need to be developed. Training in the selection and interpretation of results will also be included as part of the development to insure a consistent shared method is achieved

6.5 Retention- Knowledge Representation

Knowledge representation provides the means for capturing knowledge within the system and to perform the function of retention in an evolutionary process. Detailed in sections 4 and 5 was the deficiency of the implementation team and subsequent process improvement teams to capture the decision process and the inability to capture the tacit knowledge about the process that remained with the participating individuals. Capturing the decision process provides a means to capture lessons learned as well as creating a historical record of the evolutionary process. It provides the means and understanding of why decisions were made and therefore provides retention of the variations that were identified as being valued. Many times the teams would create procedural documents to define the boundary processes but not include the dependencies and differences that led to the selection and development of the boundary processes created. This lack of knowledge representation does not provide sufficient understanding of retention to allow the users to evaluate future variation and the impact it may have on previous, beneficial variation. The results are the introduction of future changes that may lose or degrade previously introduced variation thereby resulting in reduced performance. An example of this condition was provided in section 4.2.2 in the case of reflow temperature. Previous analysis resulted in an optimized change (variation) to the reflow temperature. The knowledge transformation that result in the new temperature was not captured. Over time additional changes (variation) were introduced resulting in the optimized temperature not being retained and performance of the reflow operation to degrade.

Boundary objects: Before knowledge representation can be designed the following previously defined boundary objects would be required:

- ***Process flow map*** to identify the knowledge required and the knowledge being generated. This was developed as part of the Process Development methodology.
- ***Defined goals*** developed as part of the Process Development methodology should establish the intent and contractual obligations of the knowledge being generated.
- ***Process of Value engineering*** should attempt to quantify the value in the knowledge being generated and how that value is captured.

Databases were plentiful and the amount of data stored extensive. Functional groups within each business unit maintained their own local database to store information identified as important to their job function. Most of the databases were not linked and access to databases by other than the owners' was extremely difficult and time consuming. Data that was retrieved had been stored to reflect the information critical to the functional group that owned the data. Re-combining information from several databases to re-create knowledge generated from investigations, or other activities coordinated by several functional groups was nearly impossible due to missing data.

Critical to the performance of knowledge representation is the consolidation and coordination of the numerous databases into a ***central repository***. As part of this process each database should be evaluated as to the value added by maintaining the database. The cost to store, maintain and access the data should be evaluated against the value gained from the re-use of data. Not all data is valuable. Data that is non-value added, incomplete, or outdated by new sources of novelty are some examples of information that does not need to be captured. The valuation of data is intended to reduce the amount of data being stored and potentially the number of databases being maintained. The validation of the knowledge representation process would be assigned to the validation team described in section 6.4. This team would insure the process steps assigned to the coordination and capture of knowledge are being followed and that the value (effective re-use) anticipated is being achieved. Once this has been accomplished the next task is to link the databases and to open the access so that all who might benefit from its knowledge will have access to it. Access can be controlled/limited to insure only those that need or will benefit from it have access. This will reduce support required and minimize the misuse or misinterpretation of information.

By creating an opened, linked database it will also increase the responsibility to coordinate how the data is being stored. As individual, locally owned and configured databases the information stored was organized for the retrieval and use of its owners. To consolidate the databases the information would have to be stored with multiple users in mind. The development of a ***standard report or format*** that promotes a common syntax and captures sufficient semantics (dependencies and differences) will be required to represent the knowledge. This will increase storage cost and complexity by requiring additional information necessary for each user to be able to retrieve, understand and value the data. This cost would be offset by the reduced amount of data stored, reduced cost to access and the increased value to multiple functional organizations.

6.6 Summary

The intent of the research and paper presented was to provide a boundary analysis of the insertion of a new technology (commercial plastic components) within a large company (Hamilton Sundstrand). The research provided analysis on the implementation of the new technology initiative and the resulting complications that developed over the lack of process steps assigned to the coordination and capture of knowledge are being followed and that the value (effective re-use) anticipated is being achieved. Once this has been accomplished the next task is to link the databases and to open the access so that all who might benefit from its knowledge will have access to it. Access can be controlled/limited to insure only those that need or will benefit from it have access. This will reduce support required and minimize the misuse or misinterpretation of information.

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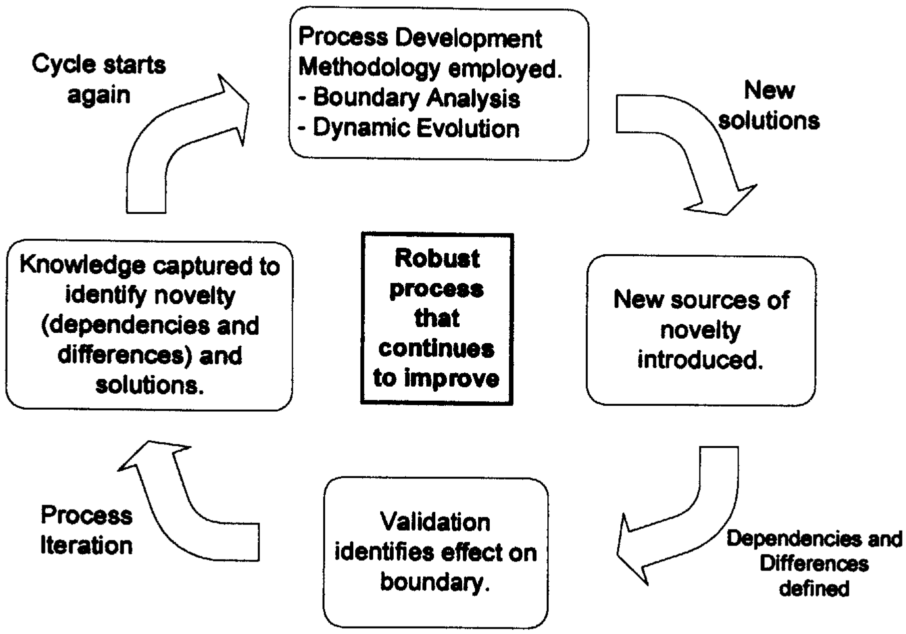

Figure 6.6-2 Proposed New Development cycle

Table 2 Boundary Objects and Ends provides a summary of the functions, recommended objects and the desired ends the objects are attempting to generate. Figure 6.6-2 Proposed New Development cycle shows the modified development cycle as it attempts to resolve the barriers identified. A high level review of the objects shows their following intent:

- Through the use of standard procedures, methods or flow maps capture the knowledge that clearly identifies the dependencies and differences of the boundary processes. This will provide a consistent reference as to the intent and execution of knowledge transformation. This is critical as novelty is introduced. The technological novelty introduced builds on old knowledge and therefor does not create obsolescence concerns. More problematic is organizational novelty as boundary users are changed and new players introduced. By capturing the knowledge of how the process functions it will allow the new users to learn through reviewing the boundary objects. By capturing the knowledge of the development of the process it will also allow the users to clearly assess the impact of new sources of novelty. Finally, the standard procedures, methods and maps provide boundary objects around which to iterate. They will provide the basis on which to grow and evolve the process.

- The process of validation was not effective at providing a warning that the boundary was degrading. By setting clear goals and establishing effective global metrics you will be able to monitor the effectiveness of the transfer and transformation of knowledge into new solutions. An example of this would be establishing metrics to monitor the recurrence of investigations in the failure analysis process. This clearly indicates the long-term effectiveness of corrective actions, which was the primary goal of the process.
- Through the identification of the clockspeed in the system it forces the user to be aware of the new sources of novelty. By developing a process that clearly identifies the steps for iteration and knowledge capture you are insuring that the process developed will be less complex but more flexible. Requisite variety and experience will also be critical. This allows the system to focus on the novelty that will be introduced during the period established by the frequency of iteration. The old system was static and therefor tried to estimate the novelty that might be introduced over a much longer period of time. This resulted in a larger, more complex but less adaptable process.

The end result is a cycle that develops a dynamic process that can identify novelty, validate its effect, and absorb it as the process evolves to become more effective in the new environment.

6.7 Recommended follow-up activities

The main focus of the paper was the use of boundary analysis as a tool to evaluate and understand the transfer of knowledge and process effectiveness. This is only one of several major effects on the transformation of knowledge. Organizational issues that address the political, cultural and strategic aspect of boundary effectiveness also needs to be addressed if a complete understanding of boundary and process effectiveness is to be achieved. The research developed here was narrowed to allow focus on the more critical boundaries involved. To complete the analysis on the implementation of a new technology initiative all major boundaries, such as those created by engineering, purchasing, and the geographically dispersed functional groups needs to be addressed.

Finally, the process development methodology put forth was a skeleton framework and needs to be developed to provide a consistent benefit. Hamilton Sundstrand has not created a process development methodology to deal with the organizational and knowledge management issues of a process and would benefit substantially from this type of research.

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Appendix A: Survey Questionnaire

Name:
Position:

Group:
Yrs of experience:

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1. What databases, that your group owns or coordinates, do you use to store data about technology, component defects or quality information on commercial components: Please list database and format (i.e. paper, Microsoft excel, MS Access etc.)

2. Who do you supply data to, or is dependent on your data (your data may help/effect them):

3. How do you receive information on new component technologies or quality problems? Please check all that apply and approximate percentage of data you receive this way:

Database	☐	%	Memos (informal)	☐	%	Reports (formal)	☐	%
Meetings	☐	%	Word of Mouth	☐	%	During Investigations	☐	%
Personal research such as Internet or journals				☐	%			

Other (please specify):

4. What functional groups supply you with this information?

5. What problems do you have with data that is supplied to you or data that you need? Please check all that apply:

Data not understood (unclear)	☐	Data late in being received	☐
Data to general (not applicable to you)	☐	Data sent to the wrong person/group	☐
Insufficient time to assess impact of data	☐	Data (or database) to difficult or inconvenient to link into	☐
Not clear who is responsible for implementing the knowledge or lesson learned	☐	The group responsible for the information was not aware that you needed or relied on this data	☐
Knowledge not captured (lesson learned only informally implemented)	☐	Data not detailed enough to be able to assess impact to group	☐

Other (please specify):

6. Who has responsibility for being aware of new component technology?

7. Who has responsibility for being aware if/how new technology impacts your job?

8. Who has responsibility to insure that the process, which involves commercial components, is robust and that improvements are being incorporated as they are identified? Please be as specific as possible listing groups and tasks as required:

   Is this Happening? If not why don't you think it is happening?

Appendix B: Interview Questionnaire

Where did the idea to build product with commercial grade plastic encapsulated modules (PEMs) originate?

What was the strategic initiative of going to (PEMs)?

Why didn't HS identify plastic parts as an opportunity to be more competitive?

What concerns were there about going to PEMs?

- Reliability, Customer acceptance
- Field experience and information

How was the decision made to go to PEMs?

- How was the knowledge developed to be able to make informed decisions?
- What information was determined to be critical?
- How was the information brought in?
- How was the information disseminated out to appropriate groups?
- What functional groups were involved? What managerial levels were involved?
- Was the decision unanimous?

When the decision was made to use PEMs what evaluation was done to assess impact to present manufacturing capability?

- Equipment impact, Process impact
- Expertise (knowledge from training and experience)

How was the decision implemented?

How was the decision communicated/recorded?

What specific changes were made to your functional group and the way you normally conducted business?

- Goals and expectations of your group?
- Process changes?

What mechanisms were put in place to monitor (revisit) the success and or barriers incurred due to the decision to incorporate PEMs?

How would you rate the implementation of PEMs within Hamilton Sundstrand's manufacturing and competitive strategy?

What do you think has happened over the past several years to complicate the PEM initiative?

What do you attribute the recent quality concerns over our PEM processes to?

Appendix C: Interview Statistics

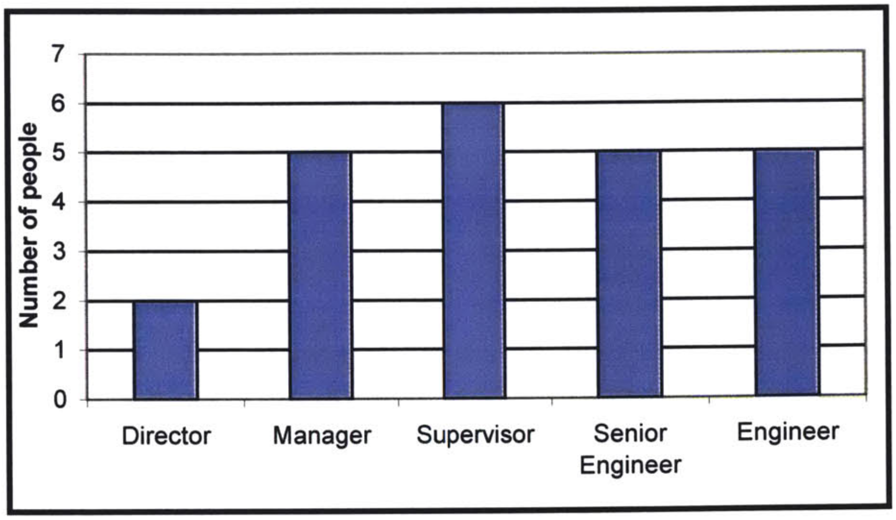

Figure 6.7-1 Interview statistics: Pareto by Job Description

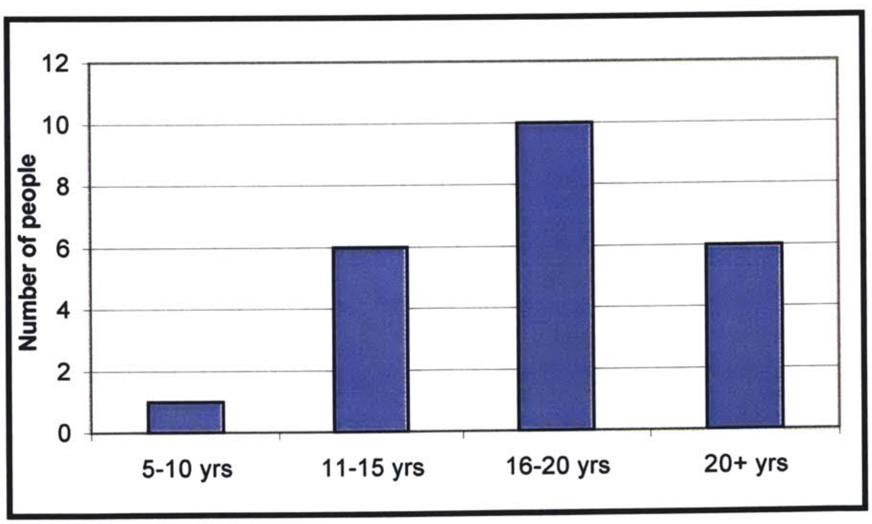

Figure 6.7-2 Interview statistics: Pareto by yrs of Experience

Boundary Type	Barriers (section 4.0)
Syntactic	• Lack of Boundary awareness • New sources of Novelty • Path Dependency • Weak syntactic boundary due to focus on Semantic boundary. • Data being stored is 'Localized' data • Excessive number of local databases • Insufficient manpower at boundary
Semantic	• Lack of Boundary awareness • New sources of Novelty • Path Dependency • Focus on differences at boundary and not dependencies • Not capturing knowledge outlining decision process • Insufficient experienced manpower at boundary • Inability to coordinate large quantities of information • Lack of objects representing dependencies and differences • Weak syntax boundary
Pragmatic	• Lack of Boundary awareness • New sources of Novelty • Path Dependency • Weak syntactic and/or semantic boundary • Not capturing knowledge outlining solution process • Focus on dependencies at boundary and not differences • Lack of objects to manipulate dependencies and differences. • Lack of teams to develop and negotiate new solutions • Insufficient experienced manpower with attitude to 'think out of the box'
Iteration	• Iteration rate to low • Process developed is static and to complex • Proper mix of static and dynamic elements not incorporated into process. • Validation does not identify degradation of boundary.

Themes	Elements of Theme (section 5.0)
Boundary awareness	• New sources of Novelty • Insufficient Manpower • Need for Requisite Variety • Focus on differences over dependencies at syntactic and semantic boundary
Path dependency	• Focus on dependencies over differences • Lack of Requisite variety • Having the right people, boundary tools and attitude • Selection of local metrics while trying to evaluate global processes
Dynamic Process	• Novelty not planned for or encouraged • Development of a static process in a dynamic environment • Trying to handle new sources of novelty with large, complex processes instead of smaller, flexible processes • The aggravation of latency in failures
Knowledge Representation	• Storage being done with local, 'Localized' databases • Tacit knowledge not captured • Value of knowledge not identified • Planning for knowledge capture not being done

Table 1 Boundary themes and Barriers

Function	Object	Desired End
Process Development methodology	• Standardized method for process development • Setting of Goals • Process flow maps • Process to perform value engineering •	***Establish and document a consistent process to build upon.*** ***Understand what the goals are and how the process accomplishes these goals.***
Evolution (Iteration)	• Process flow maps • Definition of Clockspeed (External and Internal)	***Understand where in the process novelty is being introduced.*** ***Identify the source, magnitude and rate of the novelty being introduced to understand the iteration rate required to handle the novelty.***
Variation (Novelty)	• Requisite variety planning • Process flow maps • Standard procedures • Specifications • Models	***Develop the knowledge to understand the novelty.*** *Clearly identify and communicate the dependencies and differences created by the novelty.* ***Develop tools to be able to evaluate solutions and negotiate trade-offs.***
Selection (Validation)	• Process flow maps • Defined goals • Integrated engineering teams • Standard measuring method • Balanced scorecard	***Understand expectations of the system.*** ***Utilize cross-functional team to perform the evaluation.*** ***Employ a consistent process for measuring and communicating the results of validation.***
Retention (Knowledge Representation)	• Central repository • Standard failure investigation report • Standard procedural format	***Capture data in a convenient, central location that is shared by boundary users.*** ***Utilize standard forms and procedures to insure the appropriate information is being stored in the database or procedure. Insure dependencies and differences are captured to allow future users to develop effective solutions.***

Table 2 Boundary Objects and Ends