Using Virtual Business Systems to Drive Lean Behavior in Engineering Design and Support

By

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B.S, M.Eng., Electrical Engineering & Computer Science, Massachusetts Institute of Technology, 2001

Submitted to the MIT Sloan School of Management and the Engineering Systems Division in partial fulfillment of the requirements for the degrees of

Master of Business Administration
And
Master of Science in Engineering Systems

In conjunction with the Leaders for Manufacturing Program at the
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June 2008

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Abstract

Virtual Business System (VBS) is a visual-based analytics and real-time information displaying system. It first started at Raytheon's Andover manufacturing facility in early 2000 with the strategic objectives of linking Lean and Six Sigma behavior to customers' successes and gradually transforming Raytheon into a Lean workplace. VBS dashboards are projected onto flat screen panels located throughout the factory floor such that anyone on the floor can view the production line status in real-time.

This thesis focuses on developing a new VBS dashboard and using it to transform the enterprise. Leveraging the success in manufacturing deployment, this thesis describes Raytheon's initial attempt of extending VBS to the engineering arena, with the goals of driving Lean and Six Sigma behavior to the next level, transforming problem solving behavior from reactive to proactive and from containment to prevention, redefining quality control and performance metrics to better reveal business risks and opportunities and eliminating undesirable aspects in cost, cycle time and information latency.

The VBS dashboard described in this thesis provides root cause "drill-down" capabilities for quality control and performance assessment, which leads to cycle time reduction, early stage problem resolution and defect prevention. VBS changes data ownership culture from privatize to publicize, which couples employees' actions to responsibilities and enhances proactive problem solving attitude. VBS dashboard is also a one-stop shop for data collection and analysis, which eliminates non-value added work for processing and fetching data from multiple sources. Last but not least, VBS dashboards build on modular development architecture, which enables quick turnaround on deliverables. Therefore, VBS is considered the "disruptive technology" of many existing corporate information technology systems and the Andon boards.

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In addition, thank you to Charles Mullins, Debbie Murphy, John Gould, Paul Danello, and many other IADC employees who helped me to identify risks and opportunities in my project and collaborated with me in developing the VBS dashboard. Thank you to my thesis advisors, Professor Deborah Nightingale and Professor Roy Welsch, for their guidance and support throughout the internship and their feedback and recommendations during the preparation of this thesis.

Finally, the most important thank you goes to my family. My mom is always by my side supporting me all these years. My dad is always proud of me and believes in me. My aunts and uncles always encourage me and my late grandparents always loved me.

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1 Introduction

Performance, relationships and solutions: These are the pillars that have supported the company's progress – and these are the principles, combined with our process discipline, that continue to deliver strong results.

– Raytheon Annual Report

This chapter gives an overview of the burning platform and the expected author's contribution in this internship project. It also gives the background of Virtual Business System (VBS) – the foundation of the application developed in this thesis, and previous VBS projects done by LFM students; the overview of Raytheon – the company which sponsored this fellowship; and Raytheon Six Sigma (R6σ[1]) – the foundation of this thesis.

1.1 Problem Statement – "The Burning Platform"

As Lean and Six Sigma principles became popular and have shown successes in manufacturing, Raytheon is extending Lean principles to other business units, including engineering units and the back office units such as finance and human resources.

While Lean and Six Sigma principles are tangible on manufacturing floors, the nomenclatures and methodologies can be quite ambiguous on the engineering side. Currently, Raytheon's engineering units practice Lean via Capability Maturity Model Integration (CMMI[2]). CMMI is a process improvement approach originated from the Software Engineering Institute of Carnegie Mellon University. It is a model of best practices for process integration and product improvement. It provides guidance for creating, measuring, managing, and improving specific processes.

Raytheon's CMMI initiative came directly from Dan Smith, the President of Raytheon's Integrated Defense Systems (IDS, where this internship took place), and its

[1] R6σ is registered in the United States Patent and Trademark Office (USPTO).
[2] CMMI from CMU (1997): http://www.sei.cmu.edu/cmmi/

customers. Raytheon has passed four levels (Initial[3], Managed[4], Defined[5], and Quantitatively Managed[6]) of CMMI. This year, Raytheon is reaching the goal of Level 5 (Optimizing[7]) – the highest level in the CMMI model. Once achieving this level, Raytheon's standardized and well-defined business processes will be linked directly to the desired business results. There will also be a feedback mechanism in place to continually improve performance. Finally, and most importantly, customers will have higher confidence on Raytheon's deliveries.

With the Lean, Six Sigma, and CMMI in place, Raytheon has most of the raw materials to tackle the burning platform created by the ramp-up of defense and homeland security orders in missiles and radars from the beginning of this decade. However, Raytheon still misses an automated and standardized system to assess quality and performance in both manufacturing and engineering divisions. This leads to the birth of VBS (described in Section 1.2) in the early 2000. VBS helps to reveal and identify risks and opportunities in manufacturing life cycle. It also helps to ensure a smooth production schedule, and thus to improve bottom-line performance.

This project is Raytheon IDS' initial attempt of extending VBS to the engineering organization with the hope of driving Lean and Six Sigma behavior to next level within the engineering community. The goal of this project is fourfold as shown in Figure 1:

1. Develop a brand new VBS dashboard to monitor and analyze engineering metrics and help drive Lean & Six Sigma to next level

[3] Level 1 (Initial) - Process is unpredictable, poorly controlled, and reactive.
[4] Level 2 (Managed) - Process is characterized for projects and is often reactive.
[5] Level 3 (Defined) - Process is characterized for the organization and is proactive.
[6] Level 4 (Quantitatively Managed) - Process is measured and controlled.
[7] Level 5 (Optimizing) - Focuses on process improvement.

2. Transform problem solving behavior from reactive to proactive and from containment to prevention
3. Redefine performance metrics to better reveal business risks and opportunities
4. Better align resources and eliminate undesirable aspects in cost, waste, cycle time, miscommunication, and information latency

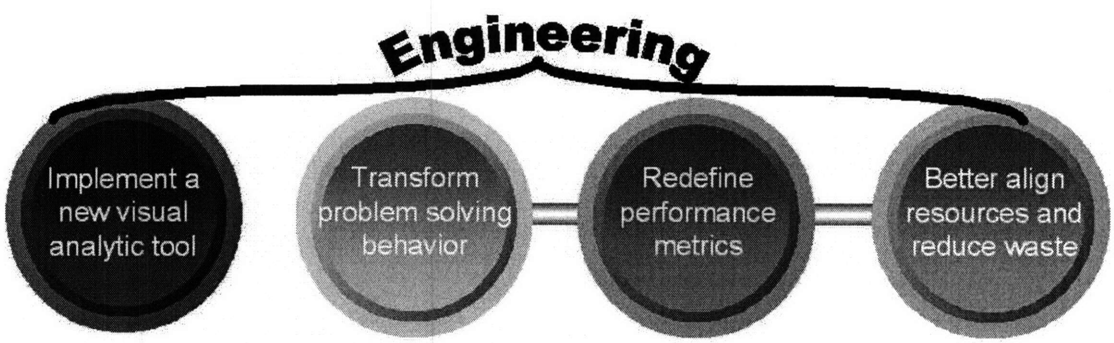

Figure 1. The 4 Project Goals

1.2 Virtual Business System (VBS)

VBS is a visual-based analytics and real-time information displaying system. It first started in early 2000 with the goal of driving uniform behavior, changing a reactive problem solving attitude to a proactive problem solving attitude and gradually transforming Raytheon into a Lean environment.

The VBS Team is a Lean technology and operations organization, independent from corporate IT. Currently, there are only two major employees (the lead and the chief engineer) running the team, together with four transient employees (they are either part-time or student interns, including the author). In addition, the VBS Headquarters was just strategically relocated to an area between the manufacturing factory floor and the administrative building, right next to the corporate dining center within the Andover manufacturing facility (where this internship took place). This symbolizes VBS is bridging the gap between operational excellence and business goals. It also signals that

VBS is expanding its enterprise boundary[8] **from the manufacturing division to the rest of the company**. This high-traffic and convenient location allows many visitors from different divisions to frequently visit. The entire team is also co-located and conducts internal and customer meetings in the Headquarters. This further enhances team cohesion and customer relationships.

VBS is connected to over 40 different databases within Raytheon, with over 85 flat screen panel real-time displays deployed throughout Andover's factory floor and 2,600 installations on manufacturing operators and cell leads' PCs. While VBS was mostly deployed in manufacturing and obtained big success in that arena, efforts are being made to **extend VBS into the engineering community**, which is the theme of this thesis.

VBS was developed on the LabView[9] platform. Currently, VBS produces dashboards to collect and display manufacturing data in real-time. The manufacturing data is collected directly via the existing Shop Floor Data Management (SFDM) system. With the database server located locally in Andover, data can be refreshed at real-time rates.

VBS dashboards are projected onto flat screen TV panels located throughout the factory floor (as shown in Figure 2), such that anyone (including visiting customers) on the floor can view the data shown on these dashboards in real-time. The real-time metrics available publicly on VBS dashboards enable efficient and proactive problem solving mentality as the information ties people's actions to responsibilities. Furthermore, VBS shortens the lead time of data collection and processing by management and floor workers. This returns them the free time for problem solving and other value-added work.

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[8] Ricardo Valerdi, Deborah Nightingale, and Craig Blackburn: Enterprises as Systems: Context, Boundaries, and Practical Implications, Conference on Systems Engineering Research 2008

[9] A graphical programming software development tool produced by National Instruments

Last but not least, the modular architecture design of VBS allows rapid prototyping and experimenting. Thus, VBS is considered the “disruptive technology”[10] of many existing corporate information technology systems and the Andon boards.

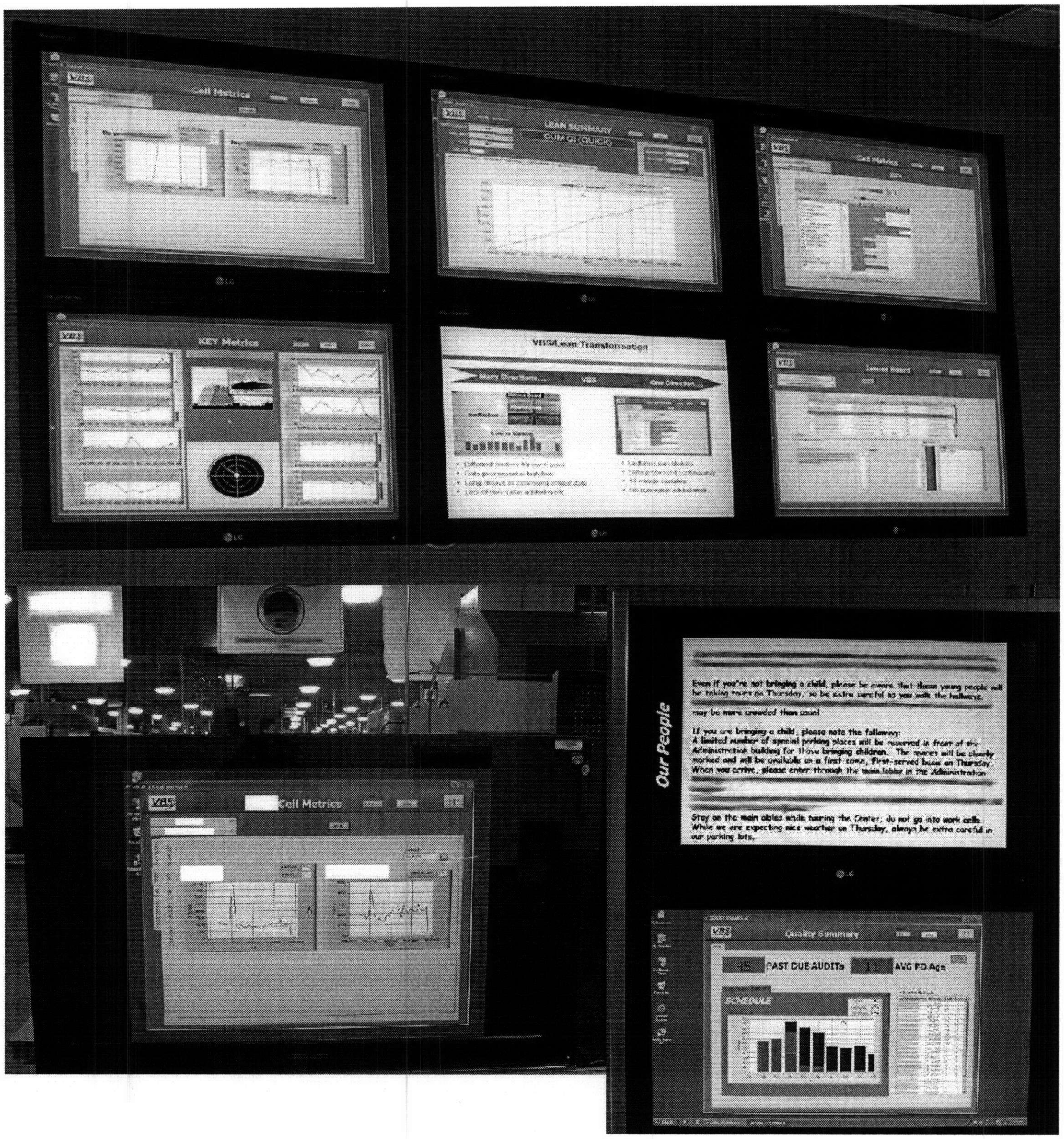

Figure 2. VBS Dashboards Displaying on Flat Panel TVs on Factory Floor

10 Clayton Christiensen: Innovators’ Dilemma

1.3 Past and Future LFM Internships on VBS

Every year Raytheon's Andover facility sponsors one to two LFM internships and some of them contribute to further developing VBS.

Dan Wolbert's[11] thesis (2007) explores VBS for part inspection process at Raytheon IADC. Prior to the introduction of VBS in this area, there was limited ability to determine how the process was performing. Downstream customers were able to track when a part entered the inspection process but were unable to predict when the inspection would be completed. VBS was introduced in the inspection area and the dashboards were displaying common Lean metrics, such as cycle time and backlog (or work-in-process). Through these dashboards the area will be able to understand how it is performing and initiate continuous improvement projects to improve performance.

Wolbert's successor, Babis Antoniou[12] (2008) developed a VBS dashboard to better assess the performance of some reviving manufacturing programs at Raytheon. This VBS dashboard reduces manufacturing costs by identifying issues earlier in the production process and allows greater communication across various stakeholders along the value chain. It also improves current manufacturing processes and eliminates various wastes, particularly the time it takes to discover issues in production and the time it takes to make educated decisions for the various risks and opportunities that arise during the production schedule.

Chip Pulitzer[13] (2008) developed a VBS dashboard on Statistical Process Control on three components: digital signal synthesizer chip, amplifier circuit board assembly, and electronic oscillator, of a manufacturing program. His dashboard was designed to

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11 Dan Wolbert (2007): Utilization of Visual Metrics to Drive Intended Performance
12 Charalambos Antoniou (2008): Using Visual Analytics to Drive Lean Behavior in Program Management Office
13 Seward Pulitzer (2008): Transitioning Technology from R&D to Production

mitigate uncertainties shift throughout the transition-to-product lifecycle and to enable new processes to be rapidly brought under control.

Neville McCaghren's[14] thesis (2005) is one of the pioneering projects in visual-based real-time data analytics deployment. He explored the idea that decision-making can be improved through automated transformation of data into information for real-time display on the factory floor. This idea resulted in several interactive dashboards in the Microwave area to improve line coordination and reduce process times for the radar sub-assembly process. The deployment lead to a 50% increase in throughput, 70% reduction in throughput variation, and a cost savings of over 600 hours per radar for the targeted processes. More importantly, the visual-based analytics tool also leads to continual process evaluation and improvement in technology and corporate culture.

There are plans for future interns to continue in transforming the enterprise and bringing VBS further upstream in the production process, e.g. using VBS to analyze and manage uncertainties in supply chain relationships, and into other divisions, e.g. Finance.

1.4 Aligning Author's Contributions to Raytheon Strategies

Raytheon's motto[15] is "Customers' success is our mission." This aligns with the corporate mission, "provide best-value solutions for warfighters and civil authorities through the affordable application of domain knowledge and the creation of purposeful business relationships." This mission also ties to Raytheon's strategic goals:

- Improve world-class performance
- Connect every employee to our business
- Create purposeful, collaborative partnerships

[14] Neville McCaghren (2005):Enable Process Improvement Through Visual Performance Indicators
[15] Raytheon's Mission Statement

- Accelerate top-line, double-digit growth
- Achieve predictable, best-in-class bottom-line performance

Raytheon's Andover facility reflected their successes in reaching these goals by claiming the North America Shingo Silver Medallion[16] in 2007 (as shown in Figure 4). The author's project also aligned to these goals, as the strategic objective of VBS is to link Lean and Six Sigma behavior to customers' successes. The idea is illustrated in the 3-gear model in Figure 3.

Figure 3. The Three-Gear Model

VBS has been fully deployed and has achieved great success in improving performance and bringing Lean and Six Sigma to the next level in Raytheon's

[16] Shingo Award is known as the Nobel Prize in Operational Excellence. It was named after Shigeo Shingo, a disciple of Taiichi Ohno.

manufacturing facilities. The author believed that VBS could expand its enterprise boundary[8], be deployed across the enterprise, and act as a major driver in connecting every employee together, driving them towards Raytheon's Lean and Six Sigma mission, and ultimately transforming Raytheon into a Lean workplace.

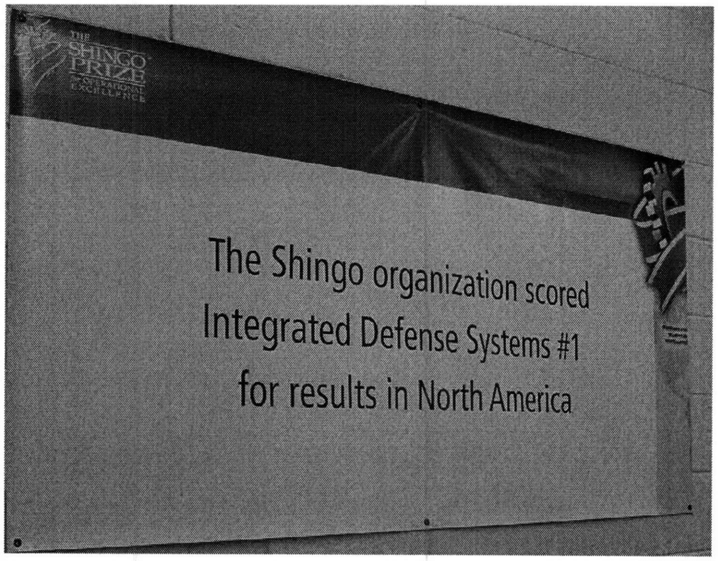

Figure 4. Shingo Prize Banner on the Factory Floor

1.4.1 The Author's Expected Contributions

The author's vision was to architect the enterprise and transform the organizational behavior in the engineering division by leveraging VBS successes in the manufacturing units. Thus, the author's contributions at Raytheon were fivefold:

1. Designed, developed and implemented a new VBS dashboard from scratch (sample programming code written by me is shown in Appendix: Figure 38, Figure 39, and Figure 40) for engineering design and support units based on customer requirements and focused on stakeholder values
2. Investigated the current data collection and data interpretation methodologies in quality control and performance assessment through the development of this new VBS dashboard and customer interaction

3. Recommended new data collection processes, quality control and performance metrics
4. Reduced cycle time, rework cost and engineering defects
5. Implemented a system that started the organizational transformation in the engineering units from defect containment to defect prevention

1.5 Raytheon Company[17] Overview

Raytheon Company is an industry leader in defense and government electronics, space, information technology and technical services. Raytheon delivers products and services to government and commercial customers in the United States and worldwide. Over 86% of Raytheon's sales in 2007[18] came from prime or subcontractor on defense related programs for the US Government, while the rest of total sales[19] were from international customers.

Founded in 1922 in Cambridge, MA, Raytheon currently has its headquarters in Waltham, MA and operates in six principal business segments:

1. Integrated Defense Systems (IDS)
2. Intelligence and Information Systems (IIS)
3. Missile Systems (MS)
4. Network Centric Systems (NCS)
5. Space and Airborne Systems (SAS)
6. Technical Services (TS)

As of December 2007, Raytheon has about 72,000 employees and 8% of them are unionized. William H. Swanson is the Chairman and Chief Executive Officer. Raytheon

[17] Materials in this section came directly from Raytheon's Annual Report 2007
[18] Total sales in 2007 is $21.3B, with $4.7B coming from IDS
[19] Equal to $4.2B of sales

is the fifth largest defense contractor (by revenue) in the world and is listed in NYSE with ticket symbol RTN. Raytheon's major competitors included Lockheed Martin, Boeing and Northrop Grumman.

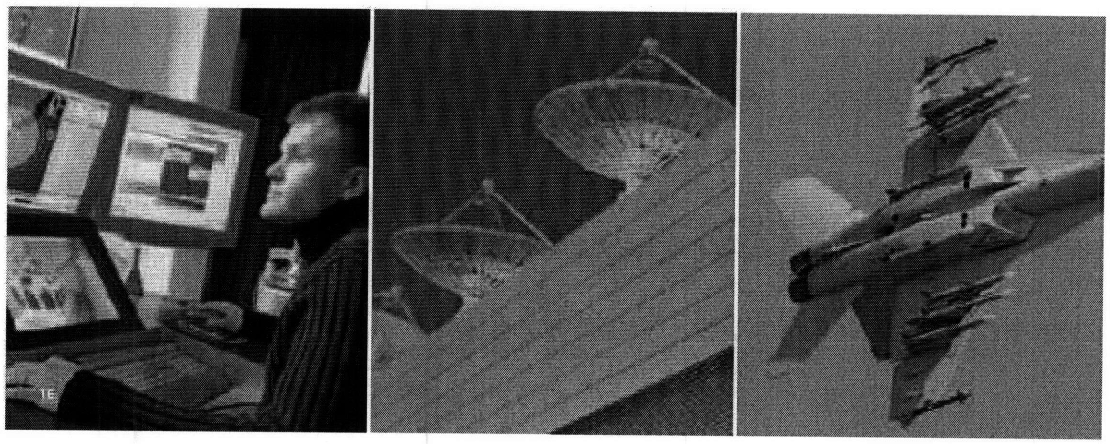

Figure 5. Raytheon's Selected Products[20]

1.6 Integrated Defense Systems

Raytheon's IDS is a leading provider of integrated joint battlespace (e.g. space, air, surface and subsurface) and homeland security solutions. IDS also expands its international business, particularly through sales of its Patriot Air & Missile Defense System, and continues to evolve its products and technologies for use in other markets. IDS' key customers include the US Navy, Army, Air Force and Marine Corps, the US Missile Defense Agency, the Department of Defense and the Department of Homeland Security. Key international customers include Japan, Saudi Arabia, Taiwan, Australia, Germany, and the United Kingdom.

The author spent six months at Raytheon's Integrated Defense Systems division in Andover, MA, USA. The Andover facility is also known as Integrated Air Defense Center (IADC). It is Raytheon IDS' major manufacturing facility for integrated whole-

[20] This picture is taken directly from the Raytheon Annual Report 2006

life air defense systems, which enable warfighters to sense, detect and engage threats through air and ground-based sensors and command and control systems.

IADC's flagship products included the Patriot Air & Missile Defense System (a long-range, high-altitude system designed to defeat advance threats, including aircraft, tactical ballistic missiles and cruise missiles), Joint Land Attack Cruise Missile Defense Elevated Netted Sensor (JLENS, a theater-based advanced sensor system that provides long-endurance, over-the-horizon detection and tracking capabilities required to defeat the threat of cruise missiles), Zumwalt Class Destroyer program (DDG 1000, America's next generation, multi-mission, naval destroyer), and the Ballistic Missile Defense Systems radars.

2 Visualize – "Imagine the Future"

If you don't know where you are going, any road will get your there.
- Lewis Carroll[21]

Visualize is the starting point of the Raytheon Six Sigma wheel (described in Section 2.1). In this step, the background of the as-is state is described and the project scope is defined. The to-be state and the project vision are also created. Both scope and vision should be aligned with Raytheon's business goals as well as customer needs.

2.1 Raytheon Six Sigma (R6σ)[22]

Raytheon Six Sigma is a knowledge-based process for transforming Raytheon's culture to maximize customer value and grow Raytheon's business. R6σ further aligns to Raytheon's business goals.

1. "Knowledge-based process": making business decisions based on facts and data using tools to conduct analysis[22]
2. "Transforming Raytheon's culture": applying R6σ to how we work and continue to transform the culture[22]
3. "Maximize customer value": R6σ process and its tools will help Raytheon to deliver customer values, thus provides competitive advantage in the marketplace[22]
4. "Grow Raytheon's business": improving decision making, strengthening culture, and value delivering to customers, in order to provide a competitive advantage resulting in winning more business[22]

[21] From Alice's Adventure in Wonderland
[22] Most of this section is directly taken from the Raytheon Six Sigma Guide

Sigma (σ) is also known as the Standard Deviation in statistics. It is a measure of variation around the average. Taiichi Ohno[23], the father of Lean Manufacturing, first introduced the Lean principles in 1950's. Quality management was then introduced by W. Edwards Deming[24] in early 1950's. He illustrated the Quality Chain Reaction in his book "Out of the Crisis". Later in the 70's Philip Crosby[25] introduced the concept of zero defects. Motorola picked it up and started the Six Sigma program, while General Electric popularized it. Raytheon Six Sigma leverages the best quality and Lean practices across industries over six decades.

Raytheon Six Sigma's principles are derived from James Womack's[26] "Lean Thinking" and Taiichi Ohno's "Toyota Production System":

1. Specify **value** in the eyes of the customer
2. Identify **value** stream; eliminate waste and variation
3. Make **value** flow at pull of the customer
4. Involve, align and empower employees
5. Continuously improve knowledge in pursuit of perfection

Value is translatable into something that customers are glad to pay for. Thus, the **value added** activity is activity that transforms material or information to meet customer requirements, while **non-value added** activity is activity that takes time or resources but does not add value to customer requirements.

[23] Taiichi Ohno: Toyota Production System
[24] W. Edwards Deming: Out of the Crisis
[25] Philip Crosby: Cutting the Cost of Quality
[26] James Womack & Daniel Jones: Lean Thinking

2.1.1 Thesis Organization

Leveraging the foundation of the Raytheon Six Sigma Process, as shown in the R6σ Wheel in Figure 6, this thesis is divided into the following six major chapters:

The starting point of the Raytheon Six Sigma wheel is **Visualize**. In this chapter, the as-is state and the project scope will be defined, while the to-be state and the project vision will be created. How this thesis fits into the overall VBS vision will also be discussed.

The second step is **Commit**. In Chapter 3, the project sponsor and stakeholders are identified and the project team is formed. As more people are involved in the project, the real journey begins and how the political lens drives the cultural lens will be discussed.

Chapter 4 talks about the **Characterize** step. The desirable and undesirable effects of data collection, data interpretation, and performance metrics as well as the information display system of the as-is state will be discussed. Their drawbacks and the associated root causes will be investigated.

The next chapter will discuss the **prioritization** of tackling the undesirable effects. The author will work together with the project sponsors to define the value stream and to focus on providing benefits to all stakeholders in the order of importance based on customer needs and undesirable effects described in the **Characterize** step.

Chapter 5 talks about the **Improve** step. The to-be (ideal) state of data collection, data interpretation, and performance metrics will be described and improvement recommendations and how the new VBS dashboard can help solving the undesirable effects of the as-is state will be discussed. The Kaizen continuous improvement activities and customers' feedback of the VBS dashboard development will also be documented.

The sixth (but not the final) and most exciting step is **Achieve**. In this last chapter, the physical and financial benefits of this VBS dashboard will be documented. The author's achievement, lessons learned from this internship and follow-up work for future VBS development will also be discussed.

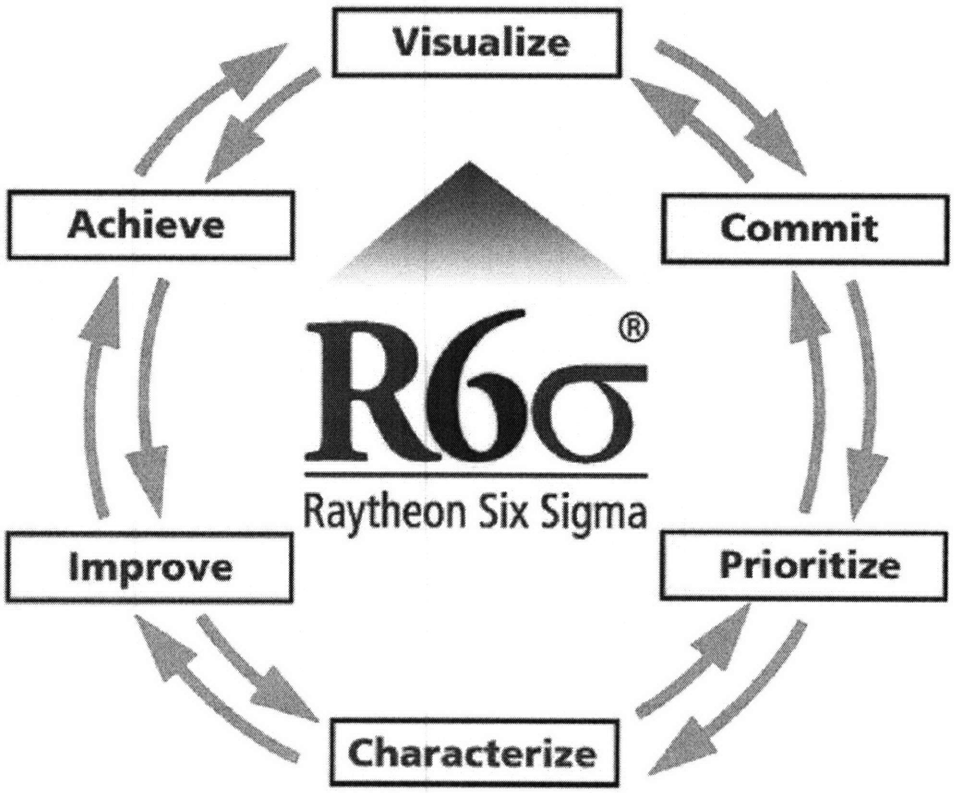

Figure 6. Raytheon Six Sigma Wheel

2.2 Project Scope

With the immediate support from customers (upper management from the engineering quality control team and the continuous improvement team), the rationale of deploying VBS in engineering units is to leverage the successful deployment in manufacturing and to naturally extend VBS culture to the engineering world, in order to enhance and engage Lean principles in this community.

Given the author's computer science background, the technical portion of this project is relatively straight forward. However, the major challenge lies in the cultural and political aspects. One of the major cultural and political issues was data accessibility and broken data linkage. Databases are "owned" and locked up by individual departments or by corporate IT (as shown in Figure 7). However, accessibility to many different databases is required in order to standardize data collection and data interpretation methodologies, re-define Lean quality control and performance metrics and re-unite them. Unfortunately, data accessibility and linkage turned out to be the major hurdle in achieving the project goal.

In addition, obtaining buy-in from engineering units was also difficult. Individual engineering units have their "customized" metrics and data processing routine but VBS is a standardized tool displaying uniform metrics. Thus, it is hard for engineering units to realize VBS' immediate benefits as they believe that their metrics and processes should be unique and different from other engineering units.

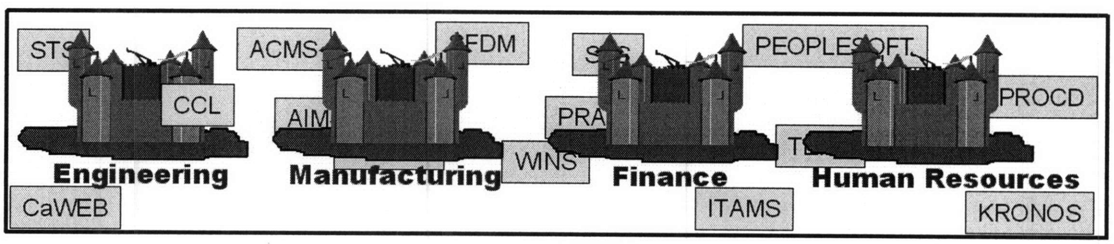

Figure 7. "Silo Operations" Behavior and Disparate Databases

2.2.1 As-Is State

The author believed that the existing static ways (e.g. posting on walls, writing on white boards, as shown in Figure 8) of presenting engineering metrics are root causes of the reactive problem solving attitude. The existing data presentation is also obsolete and does not serve the Lean vision.

The reactive problem solving behavior can at best lead to defect containment, as data needs to be collected from multiple different systems and processed in batches. This introduced long delays before the graphs were ultimately printed out and posted on the wall. This is analogous to the annual reports and end-of-quarter financial statements that companies present to shareholders. As soon as the statements were released, they were at least 3-month old. Thus, real-time company performance cannot be reflected in these statements. This is similar to the online news updates vs. the traditional newspaper, fewer and fewer people purchase traditional newspapers over the years because the news is already obsolete as soon as the papers are printed.

In addition, databases were disparate and owned by different divisions as shown in Figure 7. Given the "silo operations" practices in most large enterprises, there are lots of broken linkages in the data metrics. For example, rework hours associated with change notifications (CN)[27] is impossible to track with the current database setup as the current database only captures rework hours of all production activities but has no indications on the CN portion. Furthermore, parts can be reworked within Raytheon's manufacturing facilities or can be sent back to the suppliers but only the corresponding engineering units have the "tribal knowledge" to distinguish these two part types.

Last but not least, the existing metric presentation introduced lots of non-value added work at both division and individual levels. Not only the metrics had to be collected from different databases which increased lead time, the existing presentation also wasn't able to reveal activities at division or individual level. Thus, people have no sense of responsibility of lengthening the cycle time and slowing down the process.

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[27] Change Notification (CN) is the form which engineers fill out when they discover an issue (defect or non-defect) and need to notify other related personnel for a change in part design, drawing, or other documents.

Detailed descriptions of the desirable and undesirable effects of the As-Is state will be discussed in the Characterize phase in Chapter 4.

At Raytheon, a defect is a change in a design baseline that causes an action against a specification, test plan, drawing, schematic, parts list, part, layout, or hardware. Defects are characterized and weighted according to the phase detected. Hardware Engineering life cycle[28] in general is divided in five phases: advanced design, preliminary design, detailed design, FAIT (Fabrication, Assembly, Integration, and Test), and operations. The life cycle begins when a product is conceived and ends when the product is no longer available for use.

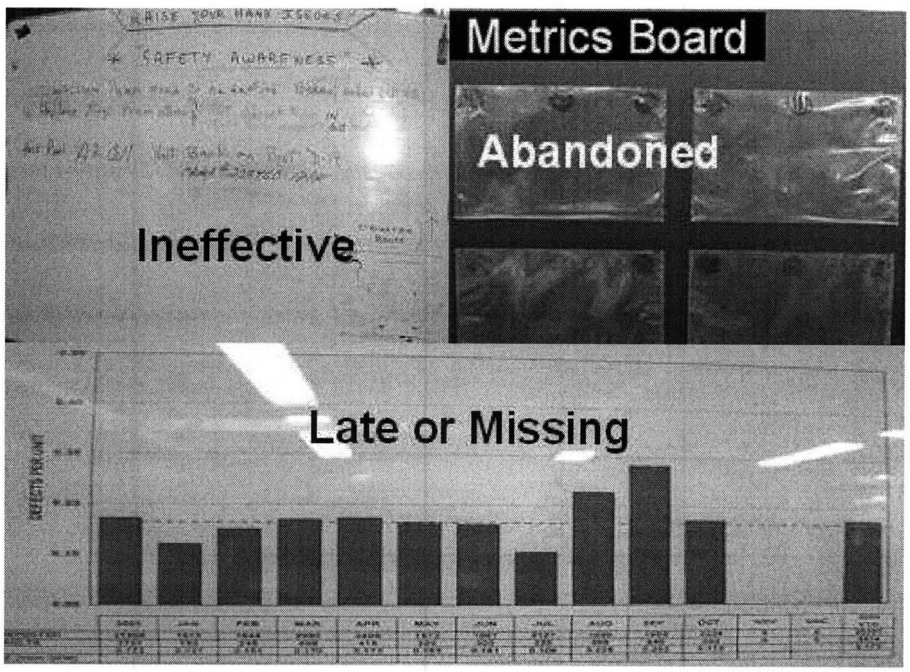

Figure 8. As-Is State of Data Presentation

1. Advanced Design: this phase identifies and assesses functional and physical solution alternatives. It includes establishment of a physical architecture and development of a decomposition structure as well as development of models

[28] Engineering Phase definitions from Raytheon IDS Hardware Engineering Life Cycle Guide

and prototypes. Standardization opportunities and make or buy alternatives are assessed in this phase as well.

2. Preliminary Design: in this phase, product and component requirements are defined and converted into an initial design, usually at the detailed, partitioned block diagram stage, ready for a Preliminary Design Review and, subsequently, for continuation into detailed design.
3. Detailed Design: in this phase, detailed specifications are converted into a documented, validated design ready for the Detailed Design Review (DDR) and, subsequently, release for production.
4. FAIT: in this phase, hardware components are built, integrated, and tested, to ensure they meet requirements prior to product integration.
5. Operations: in this phase, modifications and product improvements are introduced as necessary throughout deployment, as well as where support is provided to the fielded system with items such as tools, spare parts, technical documents, and repair and maintenance actions.

In-phase defects are those defects originated and detected in the same engineering phase; out-of-phase defects are those originated in an earlier phase but detected in a later phase. While both types of defects are undesirable and hurting bottom-line performance, the out-of-phase defects are more harmful and difficult to fix due to aging.

Defects are engineers' nightmare because they are not only difficult to measure, but the defect collection and interpretation methodologies are also ambiguous. Defects, together with engineering WIP (a.k.a. aging issues) and cycle time are the major quality control and performance toxins that engineers want to reduce and eliminate.

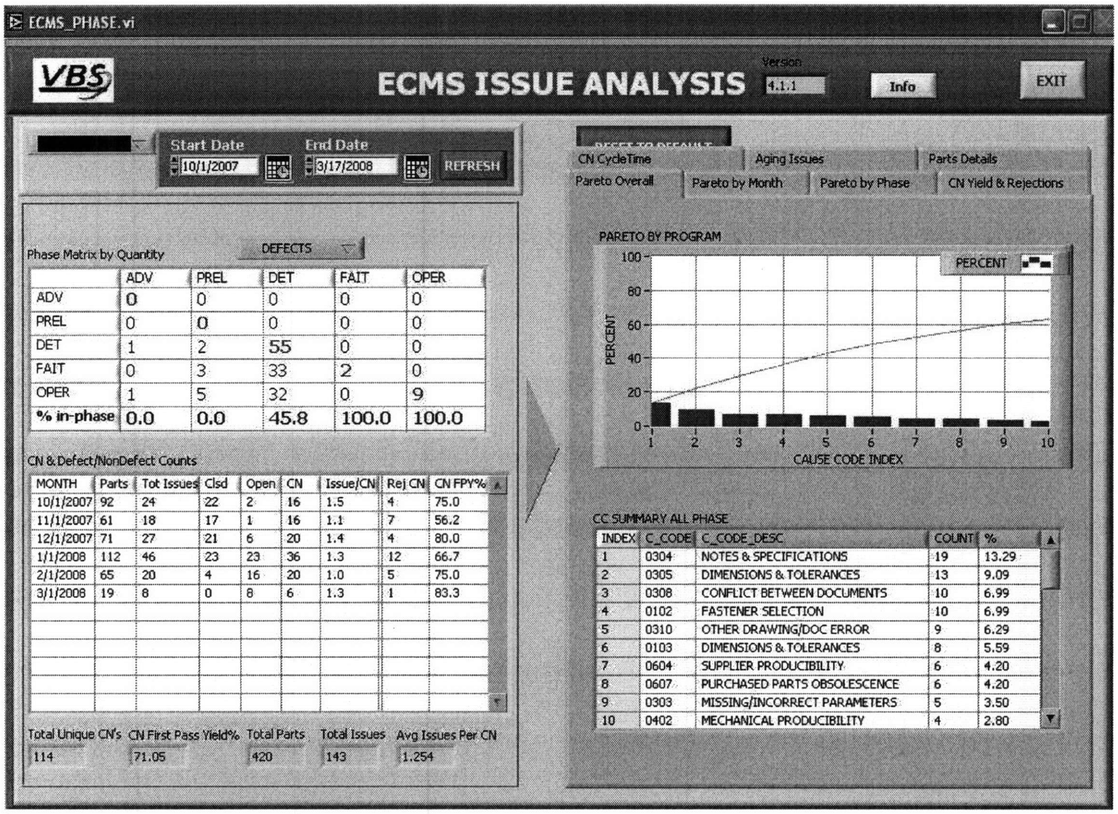

Figure 9. To-Be State: VBS Screen

2.3 The To-Be State and its Potential Benefits

This section summarizes the potential physical and financial benefits of the new VBS dashboard (as shown in Figure 9) to Raytheon IDS. This VBS dashboard (a.k.a. the to-be state) can easily contribute to a **Return on Investment (ROI) of 6X and an NPV of $5M in rework labor cost savings**. The detailed benefits and NPV analysis is described in Chapter 7.

As mentioned in Section 1.2, the vision of VBS is to help transforming Raytheon into a true Lean enterprise. Most of the previous VBS dashboards were deployed in the manufacturing arena. The new VBS dashboard designed and implemented by the author leverages the success of the previous dashboards and naturally extends VBS into the engineering world. This extension to other organizations within the enterprise aligns perfectly to the VBS vision. Furthermore, there are plans for future interns and employees to leverage the success of the author's VBS contribution in non-manufacturing and extend VBS outside the enterprise into the supplier arena.

VBS drives cost savings from two dimensions:

1. Reveal problems early in the production cycle before the problems cascaded and snowballed into bigger and costlier issues later in the cycle. This goes back to the in-phase vs. out-of-phase argument in Section 2.2.1, as defects can be predicted and even prevented with real-time data displayed on VBS.
2. Provide one-stop "drill-down" root cause analysis, which saves employees' time on data collection and interpretation, and eventually leads to savings in engineering and manufacturing rework hours, cost, aging, cycle time, and miscommunication.

The author believed that the **dynamic way of displaying multiple performance metrics and the root cause "drill-down" capability** of VBS can change problem solving behavior from reactive to proactive. VBS dashboards with real-time data are displayed on flat screen TV's mounted everywhere on the factory floor (as shown in Figure 2). This new VBS dashboard is suitable for massively deploying in the engineering labs. This deployment not only helps revealing problems earlier in the production cycle, it also helps to change data ownership culture from privatize to publicize. Revealing information to the public is the major driver in transforming organizational behavior as people's activities will be seen by everyone. This helps to connect people's actions with their responsibilities and to spread lean behavior throughout the enterprise. Given that over 6000 people in IDS are engineers, individual VBS usage can grow exponentially from 2600 to 8000. Eventually, employees will become more aware of the fact that their activities tie directly to the organization's success.

The proactive problem solving behavior not only can lead to defect containment, but can also lead to defect prevention. As a result, Raytheon can better identify risks and opportunities earlier in the engineering life cycle. This is analogous to the real-time vital sign monitoring system[29] in hospitals. Doctors and nurses can see patients' health condition on computers or handheld screens in real-time, and thus they not only can detect patients' problems and apply medical care immediately, they can also predict any potential health issues based on early symptoms provided by the real-time data and proactively work with patients to prevent more serious health problems from happening.

The new ECN[30] dashboard developed by the author will also provide many different functionalities for engineering quality control and performance assessment, including defect/aging metrics, CN[27] metrics, and cycle time metrics, and for revealing non-value added work at both the division level as well as the individual level. It will provide both reporting and "drill-down" capability, which helps engineers to better identify true bottlenecks and root causes. As a result, they can drive down defects, CN's, engineering WIP, cycle time, and rework cost.

This ECN dashboard is a **one-stop shop** for data collection and analysis by linking up the previously locked-up databases from different engineering units and corporate divisions (e.g. finance and IT) and displaying real-time data in comprehensive graphical and table format. Thus, the ECN dashboard can reduce non-value added work, shorten the lead time, and eliminate manual errors in processing and fetching data from multiple

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[29] VitalPAC, http://www.e-health-insider.com/News/2599/vital_signs_system_monitors_patients_electronically
[30] ECN is the change notification initiated from engineering division

sources. It can also significantly reduce the time between the occurrence of a fault and actions taken to correct and eliminate the fault. This is the value proposition for the ECN dashboard.

Last but not least, VBS dashboards build on modular development architecture, which conforms with CMMI[2]. This enables quick turnaround on deliverables and experimentation with customers. This capability gives VBS its competitive advantage over the traditional corporate IT's software development.

The to-be state is designed to tackle the undesirable effects of the as-is state. Recommendations and improvements will be discussed in the Improve phase in Chapter 6.

3 Commit – "Commit to Change"

Unless commitment is made, there are only promises and hopes; but no plans.

-Peter Drucker[31]

The second step of the Raytheon Six Sigma wheel is **Commit**. In this step, the project sponsors and stakeholders were identified and the project team was formed. As more people were involved in the project, the real journey begins and both political and cultural lenses should be considered.

3.1 Team Building and Sponsor Identification

The author's work team consists of the Raytheon project supervisor and his teammate, the Raytheon company sponsor, as well as the MIT team (including my faculty supervisors and LFM director). These stakeholders are indicated in white and blue in the stakeholder map in Figure 10.

The project supervisor provided full support. He was not only the coach of the project, he also helped to define the project scope and to secure project sponsors. The project supervisor has a strong vision to gradually transform the enterprise to a true Lean environment with VBS so this thesis focused on deploying VBS from manufacturing to engineering perfectly aligned to his vision. Furthermore, the supervisor's teammate (the chief developer) also fully supported the project. While he helped the author significantly on technical issues, he was not involved in addressing the organizational challenges.

The company sponsor was also fully supportive. He had a strong relationship with LFM and had strong connections with a lot of people in the company. Thus, he played a major role in lining up some project sponsors. He also helped resolving the hurdles in data accessibility when the data needed was locked-up by different divisions.

[31] From Peter Drucker's Management: Tasks, Responsibilities, Practices

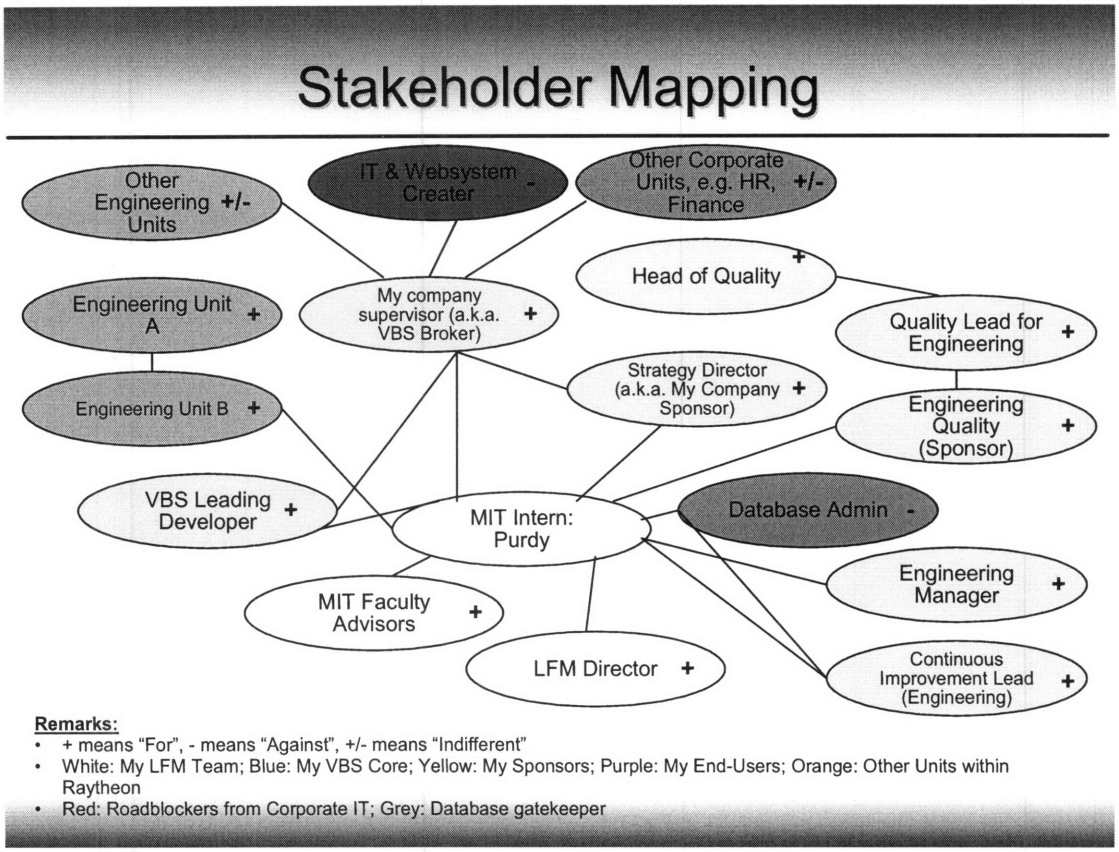


Figure 10. Stakeholder Map

The database administrator (the grey party) had a dual relationship with the author. She was the gatekeeper of the databases needed. While the author needed her help in accessing databases from different divisions, she was reluctant to share the data as she considered the author invading her territory. This hurdle in data access caused delay in the VBS implementation, thus, the data accessibility issue often required upper management's (e.g. the company sponsor) involvement to resolve. Nevertheless, she became more supportive and collaborative after realizing the value of the process.

There were three major project sponsors. They represented engineering quality management, continuous improvement, and engineering management. These sponsors are indicated in yellow in the stakeholder map in Figure 10.

The engineering quality management team behaved like the major sponsor. They were very proactive and helped prioritizing my tasks and securing buy-in from upper management. They took the top-down approach and wanted to standardize quality control metrics (mostly from defect containment and change notification perspective) across all Raytheon's engineering units and to transform Raytheon into a true Lean environment. This request aligned to the project supervisors and VBS' vision. However, their goal was to provide high-level metrics to upper management, thus, some of the designs might not be suitable for end-users (engineers).

The continuous improvement team (under Operations) was technically the major sponsor as the Operations division funded the project. They took the bottom-up approach and designed metrics from the end-users' point of view. They needed a deliverable on performance improvement (mostly from the engineering WIP and cycle time perspective) and wanted to contribute to the next Shingo assessment. They worked closely with two "quick turnaround"[32] engineering units. However, they were not as proactive as the engineering quality management team in shaping the functionalities of the dashboard.

The third sponsor was an engineering insider from the Operations division. He understood the deficiency of the existing engineering quality control and performance data collection and metrics. Thus, he was able to provide insights to the dashboard design and to drive the project's direction. He also had the vision to change the data collection and interpretation culture. He can be seen as the mentor of this project.

[32] These engineering units are on a different funding model compared to most of the defense contracts in the rest of the company. Thus, they usually need to finish projects within a few months as opposed to within a few years.

3.2 Stakeholder Analysis

The success of this thesis directly impacts VBS' reputation and Raytheon's relationship with LFM. While success has to come from all three different dimensions: upper management, customers, and peers, there are always conflicts between and within these three parties.

While I learned about "putting customers first" at Hewlett-Packard under Carly Fiorina's baton, Clay Christensen[33] implied that listening to customers too closely is the beginning of failure. Frankly speaking, both arguments are worthwhile to follow because customers really aren't always right and sometimes customers might have conflicting interests. Going back to the previous section and the stakeholder map in Figure 10, there are two major parties driving the design of this VBS dashboard. They are the sponsors (a.k.a. customers) in yellow and the end-users in purple.

With the incentive of winning the Shingo Award, the entire company is very committed to operational excellence. Their passion in reaching the Shingo Gold status in 2008 was very encouraging but their culture in data collection and interpretation was a hurdle in achieving this goal. Part of it was due to the fact that different divisions work in silos and forget to look at the big picture. Among the yellow parties, there were two schools of ideas in analyzing engineering issues: the quality control team took the top-down approach. They defined their enterprise boundary[8] at the upper management level. They obtained buy-in from upper management and focused on Change Notification[27] (CN) metrics, while the continuous improvement team took the bottom-up approach. They defined their enterprise boundary[8] by shrinking down to the engineering unit level.

[33] Clay Christiansen: Innovators' Dilemma

They obtained buy-in from engineers (purple party) and focused on driving down cycle time and engineering WIP (aging).

The VBS core team at the company (the blue party) was responsible for transforming the enterprise by developing new Lean methodologies and implementing them into VBS dashboards. However, it was sometimes difficult to prioritize among different customer needs, especially when the high-level metrics required by upper management are not necessarily what the end-users are looking for. In addition, the secondary stakeholder was taking a more proactive approach and driving the project more but the primary stakeholder was taking a back seat.

The author believed the **leader-follower relationship** was an appropriate interaction with customers. This relationship allowed the author to brainstorm and collaborate with customers. The author could also offer expert advice to customers by setting up meetings and initiating their communication. This helped to align the customers to work towards a common goal, as they indeed has a common goal but were just too focused on their own silos and forgot about the big picture. Through this relationship, the author was able to rapidly prototype and experiment on many different ideas and obtained immediate customer feedback thanks to the VBS modular architecture.

Although this project had full support from both sponsor parties, corporate IT (the red party), the business unit that developed the web-based database system displaying the in-phase/out-of-phase defects and engineering WIP metrics (samples of the web-based system are shown in Figure 11, Figure 12, and Figure 13), was not very happy about the project. They misunderstood the purpose of this project and considered it a duplication of their effort. They were also interested in developing the solutions that VBS had promised the customers (e.g. rework cost assessment). Thus, there was significant confusion and conflict concerning which division is responsible for what.

Furthermore, corporate IT owned the databases that this ECN dashboard was pulling from, thus, they had control over the data accessibility. Since they also owned the information processes, they were hesitant to disclose the formulations and were concerned that newly-defined metrics would create confusion to the existing users. The author was able to work with them to resolve these issues.

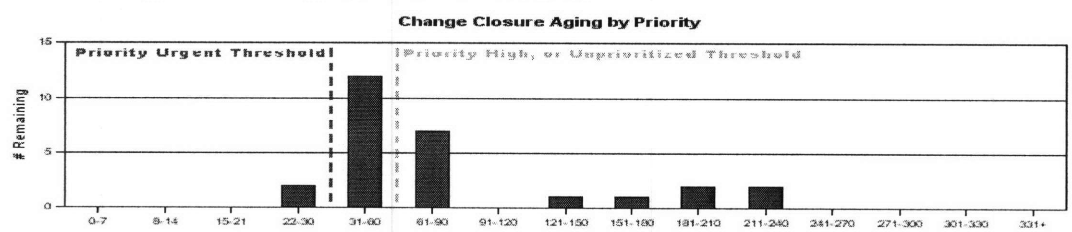
Finally, other corporate units (the orange party) believe that VBS can help them to become leaner but they are not very proactive in pursuing VBS deployment. Thus, even though VBS is getting more popular and widespread within the company, the penetration rate is still relatively slow.

HW CN Defect Containment 6/1/2007 - 3/1/2008

	Phase Originated					
Stage Detected	Advanced Design	Preliminary Design	Detailed Design	FAIT	Operations	Total
Advanced Design	0	0	0	0	0	0
Preliminary Design	0	0	0	0	0	0
Detailed Design	0	3	50	0	0	53
FAIT	0	3	37	3	0	43
Operations	0	4	37	0	1	42
Total	0	10	124	3	1	138
In-Phase Defects	0	0	50	3	1	54
% In-Phase	0.0	0.0	40.3	100.0	100.0	39.1

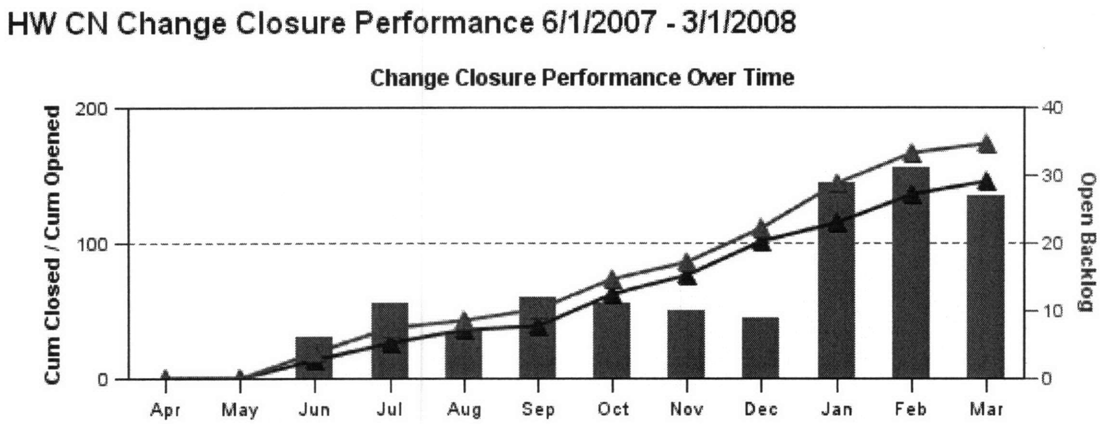
Figure 11. Web-Based Hardware Defect Containment System: Phase Matrix

HW CN Change Closure Aging 6/1/2007 - 3/1/2008



	0-7	8-14	15-21	22-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300	301-330	331+
CN	0	0	0	2	12	7	0	1	1	2	2	0	0	0	0

Figure 12. Web-Based Hardware Defect Containment System: Aging Issues



	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Open Backlog	0	0	6	11	7	12	11	10	9	29	31	27
Cum Closed	0	0	14	26	36	39	63	76	102	115	136	146
Cum Opened	0	0	20	37	43	51	74	86	111	144	167	173
Curr Deferred	0	0	0	0	0	0	0	0	0	0	0	0

Figure 13. Web-Based Hardware defect Containment System: Closed Issues

3.3 Customers' and End-Users' Buy-In

The VBS culture is to link VBS to Lean and Six Sigma thinking and to link customers' success to VBS' success. The idea can be illustrated as a tightly coupled model in Figure 14.

According to Lord Kelvin[34], "To measure is to know" and "If you cannot measure it, you cannot improve it." **While Raytheon has a strong Lean and Six-Sigma initiative, the major challenge of this project is to change the data collection and data interpretation culture. This ECN dashboard developed by the author is intended to fix the aforementioned cultural issues.** However, changing anything related to information processes and data collection requires corporate IT's approval and thus, long lead time. Obtaining buy-in from engineering units might also be difficult as VBS might be perceived as interrupting their "customized" routine. However, since they

[34] Sir William Thompson's Quote: http://zapatopi.net/kelvin/quotes/

have the goal of driving down cycle time and VBS can help them achieving this result, they are more willing to accept VBS.

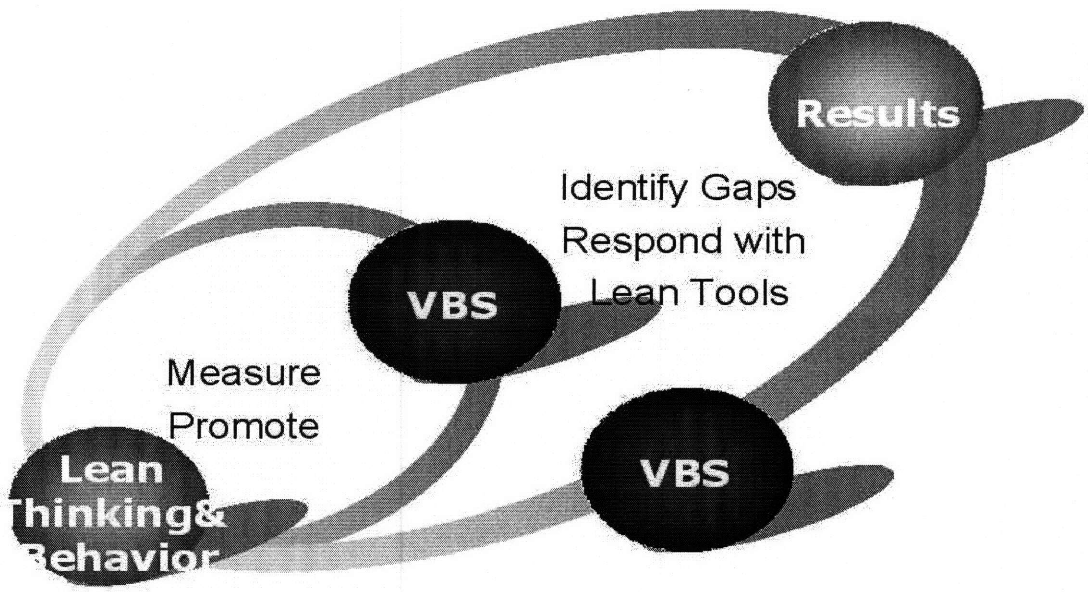


Figure 14. VBS Culture: Couple Model

The major lesson learned in this chapter is that the political lens[35] is driving the cultural lens. Thus, in order to change the data collection and data interpretation culture, different parties' interests need to be aligned and well-defined and standardized performance metrics have to be established across all engineering units such that they can all be assessed and judged on an equal footing. VBS can help to make this change and achieve customers' goals.

[35] John Carroll: The Three Lenses

4 Characterize – "Define Existing Process and Plan Improvements"

It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.

– Sir Arthur Conan Doyle[36]

The original third step of the Raytheon Six Sigma wheel is **Prioritize**. However, the author modified it and swapped it with the next step, **Characterize**, since only a few iterations can be made between these two steps within the six-month timeframe of the internship. In the **Characterize** step, the desirable and undesirable effects of the data collection, data interpretation, and performance metrics as well as the information display systems of the as-is state were described. Their undesirable effects and associated root causes were investigated and analyzed. The next chapter will discuss the prioritization of tackling the undesirable effects.

4.1 Existing Performance Metrics and Problem Solving Methodologies

While different engineering units collect data from multiple database sources and process them based on **tribal knowledge**, corporate IT has been centrally collecting hardware defect containment data from engineering units and displaying in the IDS Engineering Data Warehouse website, as shown in Figure 11 (in-phase vs. out-of phase defects), Figure 12 (engineering WIP issues), and Figure 13 (closed issues). However, this web-based system is not popular among the engineering units, probably because this system does not supply the information they needed to achieve their business goals.

[36] From The Adventures of Sherlock Holmes

4.1.1 Desired Effects of the As-Is State

The **in-phase vs. out-of-phase defects** are important metrics as discussed in Section 2.2.1. The existing web-based system does a good job in analyzing the in-phase vs. out-of-phase defects (in Figure 11). This is the reason that this feature served as the baseline of the new VBS dashboard design. When clicking on a cell in the matrix, the corresponding defect details of the selected phase of origination and phase of detection will show up (in Figure 15). VBS also has a parallel function as shown in Figure 16.

The **engineering WIP** metrics as shown in Figure 12 and Figure 13 are another desirable effect in the existing web-based system. This also served as the baseline of the new VBS dashboard design. The corresponding engineering WIP details are available when clicking the graphs in either system.

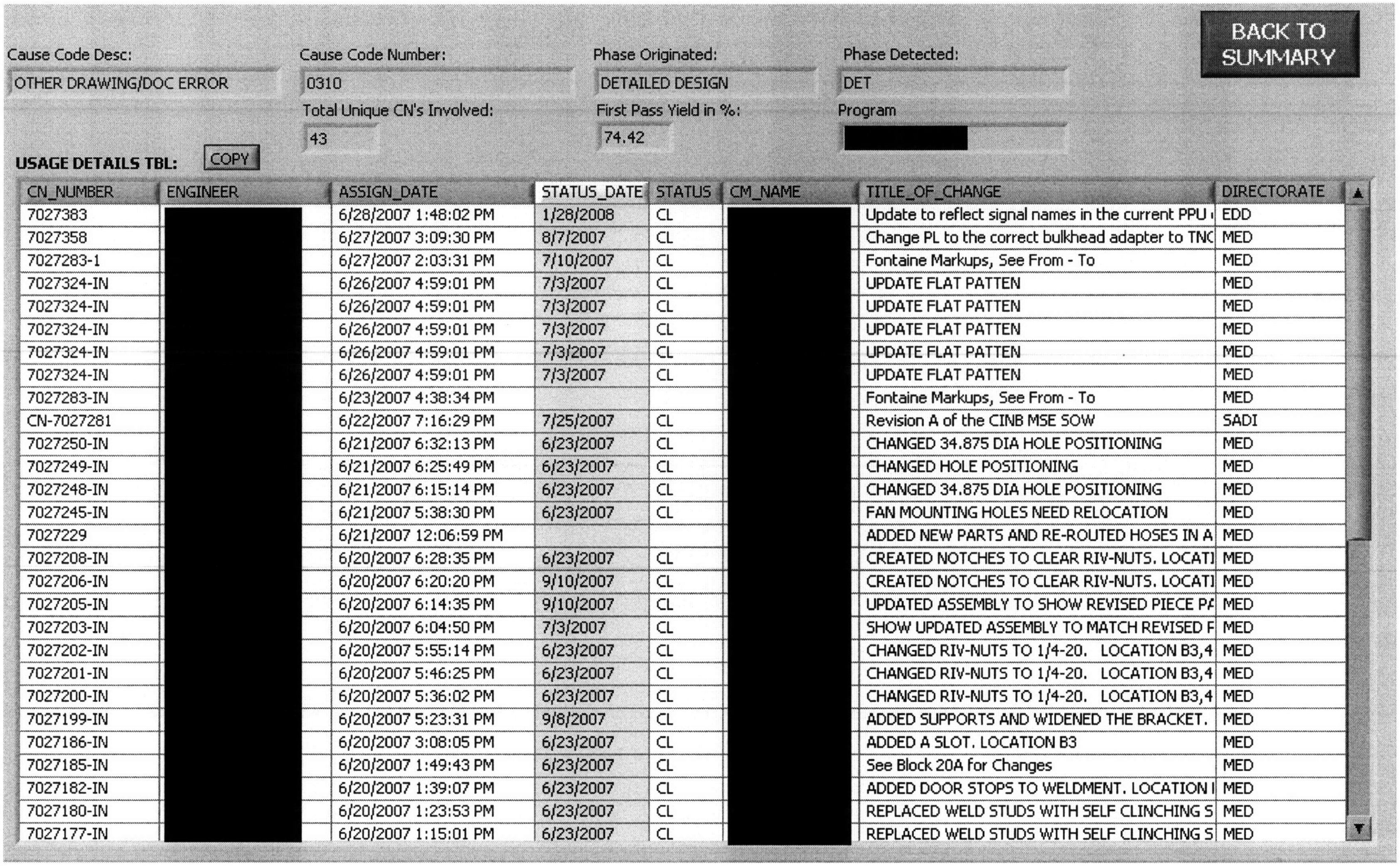
4.1.2 Undesirable Effects of the As-Is State

As discussed in Section 2.2.1, the author believed the existing **static** way of presenting engineering work progress data as shown in Figure 8 is the root cause of **reactive problem solving behavior**. While the web-based system helps centralizing data from different sources, standardizing the defect and engineering WIP metrics, and reducing the lead time in processing data, it does not address root cause analysis, CN[27] approval/rejection and cycle time analysis, and rework cost tracking.

The web-based system is a **data reporting system**. Its presentation format is not suitable for widely displaying in public. The web-based system shows data for users to **"view at leisure"** and it **does not have the root cause "drill-down" analysis capability**. Furthermore, the **long lead time** of the web-based system's implementation is also undesirable. It usually takes months to complete since it has to go through corporate IT's approval and resource allocation, as opposed to the quick turnaround of VBS.

Defect Number	Defect Item	Program	Defect Count	Review Name	Cause Code	Cause Description	Reason For Change	Summary Of Change	Origination Date	Plan Date	Outlook Date	Actual Date	Close Date	Assignee	Originator	Subsystem	Phase Detected	Phase Originated	Directorate	Discipline	Department	Priority	Status	State	Origination Type
246272	246272	[redacted]	1	NA	0805	SCOPE CHANGE - FAIT	TO INCORPORATECHGS REQD FOR ECPR1670 NOISE CANCELLER	TO INCORPORATE CHGS REQD FOR ECPR1670 NOISE CANCELLER	17-JAN-07	17-JAN-07	17-JAN-07	01-MAR-07	03/09/2007	[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	LOW	CLOSED	CL	CN
253300	253300	[redacted]	1	NA	0805	SCOPE CHANGE - FAIT	MODIFY MARKING TO AGREE WITH CG-52 REQUIREMENTS	MODIFY MARKING	15-OCT-07	15-OCT-07	15-OCT-07	05-NOV-07	11/26/2007	[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	LOW	CLOSED	CL	CN
7022147	7022147	[redacted]	1	NA	0805	SCOPE CHANGE - FAIT	Hardware added and wiring change on site.	HARDWARE ADDED AND WIRING CHANGED ON SITE. THIS CN WILL CLOSE BEALE ITR 021314. Material NWA will be provided after the site assessment is complete.	15-AUG-06	15-AUG-06	15-AUG-06	26-FEB-07	03/12/2007	[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	LOW	CLOSED	CL	CN
7030686	7030686	[redacted]	1	NA	0805	SCOPE CHANGE - FAIT	See referenced MS Word Attachments	FTS Changes required to resolve A/D and D/A sensitivity issues	06-DEC-07	06-DEC-07	06-DEC-07	30-JAN-08		[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	LOW	OPEN	OP	CN
8771	14147	[redacted]	1	TANK LEVEL INDICATOR (TLI), RADAR WITHOUT SOUNDING, P/N 9002180-2	LPD02	NA	NA	Communication took place yesterday with supplier as to why hardware was not oriented correctly durin	30-AUG-07			18-OCT-07		[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	OTHER	CLOSED	CL	CN
8771	14147	[redacted]	1	TANK LEVEL INDICATOR (TLI), RADAR WITHOUT SOUNDING, P/N 9002180-2	LPD02	NA	NA	Communication took place yesterday with supplier as to why hardware was not oriented correctly durin	30-AUG-07			18-OCT-07		[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	OTHER	CLOSED	CL	CN
8771	14147	[redacted]	1	TANK LEVEL INDICATOR (TLI), RADAR WITHOUT SOUNDING, P/N 9002180-2	LPD02	NA	NA	Communication took place yesterday with supplier as to why hardware was not oriented correctly durin	30-AUG-07			18-OCT-07		[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	OTHER	CLOSED	CL	CN
8771	14147	[redacted]	1	TANK LEVEL INDICATOR (TLI), RADAR WITHOUT SOUNDING, P/N 9002180-2	LPD02	NA	NA	Communication took place yesterday with supplier as to why hardware was not oriented correctly durin	30-AUG-07			18-OCT-07		[redacted]	[redacted]	[redacted]	OPERATIONS	FAIT	[redacted]	H	[redacted]	OTHER	CLOSED	CL	CN

Figure 15. Web-Based Hardware Defect Containment System: Defect Details



Cause Code Desc: OTHER DRAWING/DOC ERROR
Cause Code Number: 0310
Phase Originated: DETAILED DESIGN
Phase Detected: DET
Total Unique CN's Involved: 43
First Pass Yield in %: 74.42
Program [redacted]
BACK TO SUMMARY

USAGE DETAILS TBL: COPY

CN_NUMBER	ENGINEER	ASSIGN_DATE	STATUS_DATE	STATUS	CM_NAME	TITLE_OF_CHANGE	DIRECTORATE
7027383	[redacted]	6/28/2007 1:48:02 PM	1/28/2008	CL	[redacted]	Update to reflect signal names in the current PPU (	EDD
7027358		6/27/2007 3:09:30 PM	8/7/2007	CL		Change PL to the correct bulkhead adapter to TNC	MED
7027283-1		6/27/2007 2:03:31 PM	7/10/2007	CL		Fontaine Markups, See From - To	MED
7027324-IN		6/26/2007 4:59:01 PM	7/3/2007	CL		UPDATE FLAT PATTEN	MED
7027324-IN		6/26/2007 4:59:01 PM	7/3/2007	CL		UPDATE FLAT PATTEN	MED
7027324-IN		6/26/2007 4:59:01 PM	7/3/2007	CL		UPDATE FLAT PATTEN	MED
7027324-IN		6/26/2007 4:59:01 PM	7/3/2007	CL		UPDATE FLAT PATTEN	MED
7027324-IN		6/26/2007 4:59:01 PM	7/3/2007	CL		UPDATE FLAT PATTEN	MED
7027283-IN		6/23/2007 4:38:34 PM				Fontaine Markups, See From - To	MED
CN-7027281		6/22/2007 7:16:29 PM	7/25/2007	CL		Revision A of the CINB MSE SOW	SADI
7027250-IN		6/21/2007 6:32:13 PM	6/23/2007	CL		CHANGED 34.875 DIA HOLE POSITIONING	MED
7027249-IN		6/21/2007 6:25:49 PM	6/23/2007	CL		CHANGED HOLE POSITIONING	MED
7027248-IN		6/21/2007 6:15:14 PM	6/23/2007	CL		CHANGED 34.875 DIA HOLE POSITIONING	MED
7027245-IN		6/21/2007 5:38:30 PM	6/23/2007	CL		FAN MOUNTING HOLES NEED RELOCATION	MED
7027229		6/21/2007 12:06:59 PM				ADDED NEW PARTS AND RE-ROUTED HOSES IN A	MED
7027208-IN		6/20/2007 6:28:35 PM	6/23/2007	CL		CREATED NOTCHES TO CLEAR RIV-NUTS. LOCATI	MED
7027206-IN		6/20/2007 6:20:20 PM	9/10/2007	CL		CREATED NOTCHES TO CLEAR RIV-NUTS. LOCATI	MED
7027205-IN		6/20/2007 6:14:35 PM	9/10/2007	CL		UPDATED ASSEMBLY TO SHOW REVISED PIECE PA	MED
7027203-IN		6/20/2007 6:04:50 PM	7/3/2007	CL		SHOW UPDATED ASSEMBLY TO MATCH REVISED F	MED
7027202-IN		6/20/2007 5:55:14 PM	6/23/2007	CL		CHANGED RIV-NUTS TO 1/4-20. LOCATION B3,4	MED
7027201-IN		6/20/2007 5:46:25 PM	6/23/2007	CL		CHANGED RIV-NUTS TO 1/4-20. LOCATION B3,4	MED
7027200-IN		6/20/2007 5:36:02 PM	6/23/2007	CL		CHANGED RIV-NUTS TO 1/4-20. LOCATION B3,4	MED
7027199-IN		6/20/2007 5:23:31 PM	9/8/2007	CL		ADDED SUPPORTS AND WIDENED THE BRACKET.	MED
7027186-IN		6/20/2007 3:08:05 PM	6/23/2007	CL		ADDED A SLOT. LOCATION B3	MED
7027185-IN		6/20/2007 1:49:43 PM	6/23/2007	CL		See Block 20A for Changes	MED
7027182-IN		6/20/2007 1:39:07 PM	6/23/2007	CL		ADDED DOOR STOPS TO WELDMENT. LOCATION I	MED
7027180-IN		6/20/2007 1:23:53 PM	6/23/2007	CL		REPLACED WELD STUDS WITH SELF CLINCHING S	MED
7027177-IN		6/20/2007 1:15:01 PM	6/23/2007	CL		REPLACED WELD STUDS WITH SELF CLINCHING S	MED

Figure 16. VBS Dashboard: Defect Data

Even though Raytheon is at CMMI[2] Level 4, which means that standardized metrics and processes are in place, different engineering units have "customized" their metrics and processes according to their needs. In addition, corporate IT has defined and standardized the as-is quality control and performance metrics (as described below) and the data collection methodologies. This introduced the major hurdle in this internship.

Raytheon's engineers document defects and improvements in a form called Change Notification (CN[27]) designed by corporate IT. However, there are five major problems embedded in the design of CN leading to the existing data collection and data interpretation culture. These root causes illustrate a classic example of whether "Behavior drives metrics" or "Metrics drive behavior".

1. Number of CN's vs. Number of Defects: Engineers sometimes perceive total number of CN's the same as total number of defects due to the legacy from previous CN form design (older version of CN only allowed one cause code entry). However, multiple defects can be documented in the same single CN.

2. Rework Parts vs. Defect Root Cause: The lack of a 1-on-1 mapping of a rework part with a defect root cause, for example, if there are 10 rework parts documented in a single CN, there may only be 2 root causes associated with these 10 parts, leads to the issue that neither the root cause of a defect nor the total number of defects were reported accurately. This also leaves room for ambiguous interpretation as people can put many defects in the same CN and count as one "defect".

Figure 17 and Figure 18 show the first 2 pages of a CN. The second page of the CN contains two tables (an upper one and a lower one). Engineers will input the documents or parts that require rework in the upper table. They should then fill out the lower table with the corresponding root cause, a short description of the reason for change, and the phase in which the problem was originated. However, there are no constraints to force the engineers to put a root cause, a short description, and a phase in the lower table to match 1-to-1 with each part/document specified in the upper table. Furthermore, since the table was split into two, this gave engineers an illusion that the information in these 2 tables is disparate. Thus, it creates a major ambiguity as the number of defects can be interpreted and counted in three different ways:

1. Count the total number of document/parts in the upper table (i.e. Column 12)
2. Count the total number of root causes (i.e. Column 20b)
3. Count the permutations of (1) and (2)

Documents/Parts Affected & Effectivity

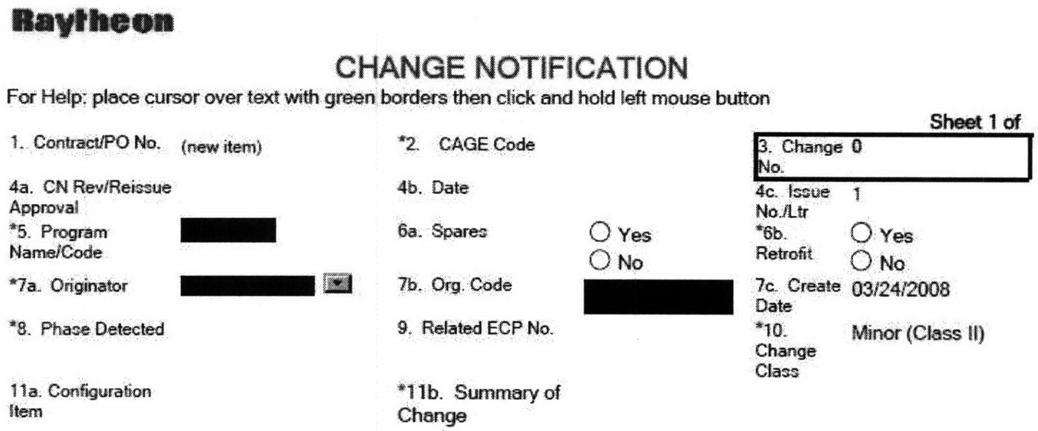
*12. Document/Part Number	12a. CN Page #	*13. Cur Rev / #	14. New Rev / #	15. Next Higher Assy / Controlled Assy / Item	16. Make/Buy Code	17. Eff. Type	18. Usage From	To	19. Disposition Disposition Definitions	

Note: If additional space is required for Document/Parts Affected & Effectivity use continuation sheet.

*20a. Reason for Change	*20b. Cause Code Cause Code Definitions	*20c. Phase Originated	*20d. Subsystem	

Figure 17. CN Part/Root Cause Table

Currently, (2) is used to count the total number of defects but it might be an undercount in many cases. A simple way to cure this ambiguity is to combine and align these two tables together as shown in Figure 19 and force engineers to fill out Column 20b if Column 12 is filled. Thus, both (1) and (2) will give the same counting.


Raytheon

CHANGE NOTIFICATION

For Help: place cursor over text with green borders then click and hold left mouse button

Sheet 1 of

1. Contract/PO No.	(new item)	*2. CAGE Code		3. Change No.	0
4a. CN Rev/Reissue Approval		4b. Date		4c. Issue No./Ltr	1
*5. Program Name/Code	[redacted]	6a. Spares	O Yes O No	*6b. Retrofit	O Yes O No
*7a. Originator	[redacted]	7b. Org. Code	[redacted]	7c. Create Date	03/24/2008
*8. Phase Detected		9. Related ECP No.		*10. Change Class	Minor (Class II)
11a. Configuration Item		*11b. Summary of Change			

Figure 18. CN Form: First Page

<u>3. CN for Improvement Suggestion vs. CN for Rework:</u> The definition of a "good" CN (for improvement suggestion) and a "bad" CN (for defects) is ambiguous. This aspect leads to the illusion that all CN's are bad as CN's are perceived as recording defects only. Similar to the cholesterol measurement, some people only judge by the combined HDL and LDL number but they forgot to separate the good and bad cholesterol. This is dangerous as the combined number is not the best indicator. Similarly, a good CN represents a product improvement notice but currently all CN's are perceived as "bad". A CN can also be used to record process improvements. However, due to the fact that engineers are not required to fill out a cause code corresponding to each rework part/document and the cause codes for process improvement are not available, improvement suggestions are either not documented in CN or are documented but are

mistaken as defects. Ultimately, Raytheon cannot properly identify business risks and opportunities.

4. Rework Cost Collection: The current data collection methodology has a broken linkage between rework parts and rework hours/cost associated with CN, due to the disparate nature of the existing databases. Thus, the actual CN cost cannot be assessed, which makes cost saving computation difficult.

5. Redundancy in Field Options: The "not applicable" option is available to be selected at the phase of origination, phase of detection, and cause code fields of a CN. These options do not add values to the root cause analysis and also encourage ambiguity. In addition, engineers sometimes complain that the cause codes do not always describe the actual problems well. Thus, they either record the defects with a wrong cause code or just simply put "not applicable".

While issues 1, 2, and 5 might be fixed relatively easily by redesigning the CN form as shown in Figure 17 (specifically to combine the upper and lower tables into one), issue 3 needs a change in data collection and data interpretation culture. In either case, it will still take time and buy-in from engineering units, upper management, and corporate IT, who defined the current defect counting metrics, in order to make it happen.

For issue 4 an approach to connect CN's to manufacturing rework has been identified and will be implemented. This will be done by linking the Shop Floor Data Management (SFDM) transaction to the ECN database as manufacturing transactions are posted on the floor. This is a very important linkage as cost saving cannot be done without this linkage. In addition, engineering units compute rework cost based on part source but there are no indications to distinguish parts reworked in-house vs. parts reworked at suppliers'. Thus, it gets more difficult to track rework cost.

Last but not least, **data is privatized and locked up by different divisions or by corporate IT** as shown in Figure 7. Thus, it often takes employees a few days to fetch data from multiple different sources and compile performance reports. This aspect introduces **a lot of non-value added work** for employees.

4.2 Root Cause Analysis

VBS provides a data-driven and visual-based analytics approach which is intended to change the problem solving mentality from reactive to proactive, from containment to prevention, and from tactic to strategic by the availability of real-time and dynamic data and the root cause "drill-down" capability.

The Fishbone Diagram in Figure 20 shows the root cause analysis of the undesirable effects in the as-is state. The "bone" labeled "C" shows that the variable is a constant. It is fixed and there is no way to exert control over this variable. The "bone" labeled "X" shows that the variable is experimental, thus, it can be altered.

Clearly, most of the variables are adjustable and can be altered by re-defining the existing metrics and processes and by deploying this new VBS dashboard in different engineering units. However, all the constant variables represent corporate IT's power. These variables are not alterable unless IT makes the change.

The lesson learned from the chapter is that being able to identify the undesirable effects and get past these symptoms to root cause analysis is the basis of problem solving and improvement. With the as-is state as the foundation to build on, the to-be state is designed to reach business goals by closing the gaps in the as-is state.

*12. Document/Part Number	12a. CN Page #	*13. Cur Rev / #	14. New Rev / #	15. Next Higher Assy / Controlled Assy / Item	16. Make/Buy Code	17. Eff. Type	18. Usage From	To	19. Disposition Disposition Definitions

*20a. Reason for Change	*20b. Cause Code Cause Code Definitions	*20c. Phase Originated	*20d. Subsystem

Figure 19. New CN Form: Combining the Upper and Lower Part/Root Cause Table

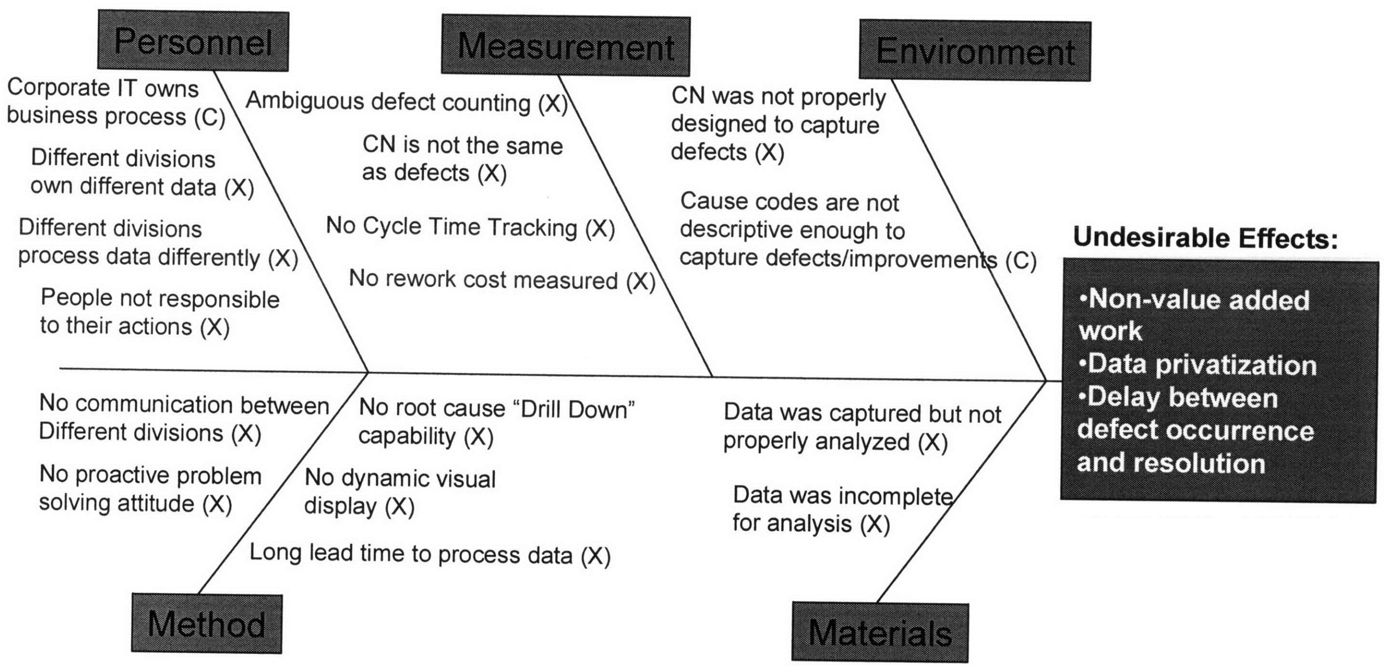


Figure 20. Fishbone Diagram: Root Cause Analysis of the As-Is Undesirable Effects

5 Prioritize – "Determine Important Priorities"

To put the world in order, we must first put the nation in order; to put the nation in order, we must put the family in order; to put the family in order, we must cultivate our personal life; and to cultivate our personal life, we must first set our hearts right.

– *Confucius*[37]

The "modified" fourth step of the Raytheon Six Sigma wheel is **Prioritize.** In this step, the author worked together with the project sponsors to define the value stream and priorities. Once the value stream was identified, benefits based on customer needs and the undesirable effects described in the **Characterize** step can be determined.

5.1 Value Stream, Plans and Schedule

Value stream is a set of all actions required to bring a specific product and/or service from concept to the point of providing value to the customers. Thus, value stream is defined from the customer's point of view. Raytheon's engineering units deal with hardware, software, drawings, and documentation issues every day. Each of these categories is assessed by different quality control and performance metrics. This new VBS dashboard was designed and implemented to tackle the undesirable effects in the existing hardware defect containment system according to customer needs.

5.1.1 Tackling the Undesirable Effects

Hardware defect is a core problem in engineering so this type of problem requires immediate attention. Within the hardware defect category, quality and performance can be assessed from multiple dimensions based on processes and activities. The seven major burning issues are prioritized according to the severity of the five undesirable effects described in the **Characterize** step. They are tackled in the following order of importance based on customer needs:

[37] From The Great Digest and The Unwobbling Pivot

1. In-Phase vs. Out-of-Phase Defects: In-phase and out-of-phase defects were already described in Section 2.2.1. Out-of-phase defects are costlier and more difficult to fix but the in-phase defects are also undesirable. Thus, the goal is to first eliminate out-of-phase defects (the black numbers on the bottom triangle of the matrix in Figure 21) and eventually to reduce in-phase defects (the blue on-diagonal numbers in Figure 21). The horizontal axis shows the five phases of origination as described in Section 2.2.1, while the vertical axis shows the five phases of detection. For example, there were 55 defects originated in the detailed design phase and were also detected in this phase, while there were 33 defects originated in the detailed design phase but were detected in the FAIT phase and 32 defects originated in the detailed design phase but were detected in the Operations phase. These results were bad as less than 50% of defects caught in-phase. This leads to costlier and longer rework hours in later production cycle.

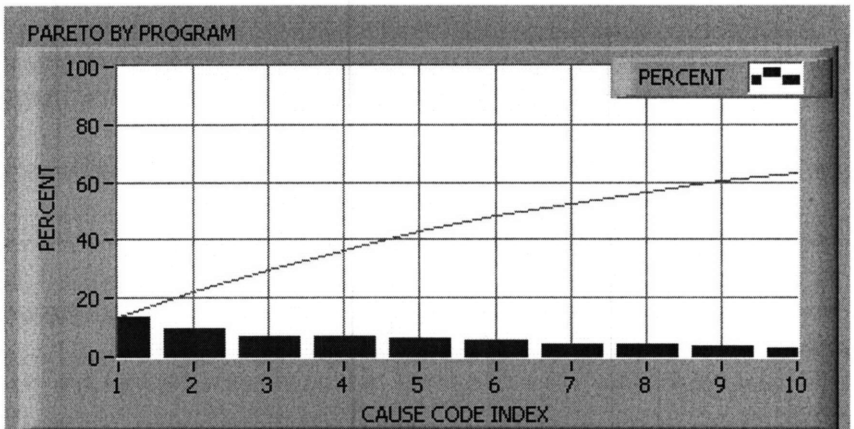
Phase Matrix by Quantity — DEFECTS

	ADV	PREL	DET	FAIT	OPER
ADV	0				
PREL	0	0			
DET	1	2	55		
FAIT	0	3	33	2	
OPER	1	5	32	0	9
% in-phase	0.0	0.0	45.8	100.0	100.0

Figure 21. In-Phase vs. Out-of_phase Defects

2. Root Cause Pareto Analysis: Each defect has a root cause. Some of these root causes are dominating in particular engineering units, particular time of the year, particular engineering phases, or particular parts. The goal is to track down these root causes and tackle them accordingly. As shown in Figure 22, "notes and

specifications", "dimensions and tolerances", and "conflict between documents" are the dominating defects of this particular engineering unit. Eliminating these three types of defects can reduce the total defect count by over 30%. On the other hand, Pareto analysis can sometimes be misleading. In this case, the dominating root causes might not be the costliest defects. Thus, cost tracking is still the most important aspect in rework elimination.



CC SUMMARY ALL PHASE

INDEX	C_CODE	C_CODE_DESC	COUNT	%
1	0304	NOTES & SPECIFICATIONS	19	13.29
2	0305	DIMENSIONS & TOLERANCES	13	9.09
3	0308	CONFLICT BETWEEN DOCUMENTS	10	6.99
4	0102	FASTENER SELECTION	10	6.99
5	0310	OTHER DRAWING/DOC ERROR	9	6.29
6	0103	DIMENSIONS & TOLERANCES	8	5.59
7	0604	SUPPLIER PRODUCIBILITY	6	4.20
8	0607	PURCHASED PARTS OBSOLESCENCE	6	4.20
9	0303	MISSING/INCORRECT PARAMETERS	5	3.50
10	0402	MECHANICAL PRODUCIBILITY	4	2.80

Figure 22. Pareto Chart of a Particular Engineering Unit

3. <u>CN Approval, Rejection, and First-Pass Yield</u>: CN[27] first-pass yield keeps track of the number of approved CN's over the total number of CN's filed in a particular period of time. It is a significant metric in quality assessment as it shows if an engineering unit filed any non-value added CN's. In addition,

customers are also interested in which particular steps of a CN were rejected the most since this shows if the gatekeeper is allowing any non-value added CN's to slip through. The black line in Figure 23 shows the first-pass yield of this engineering unit in the previous 6 months. The table below shows the Configuration Management (CM) manager, who is the first gatekeeper of CN approval, has done a decent job in filtering value-added CN's from non-value added CN's.

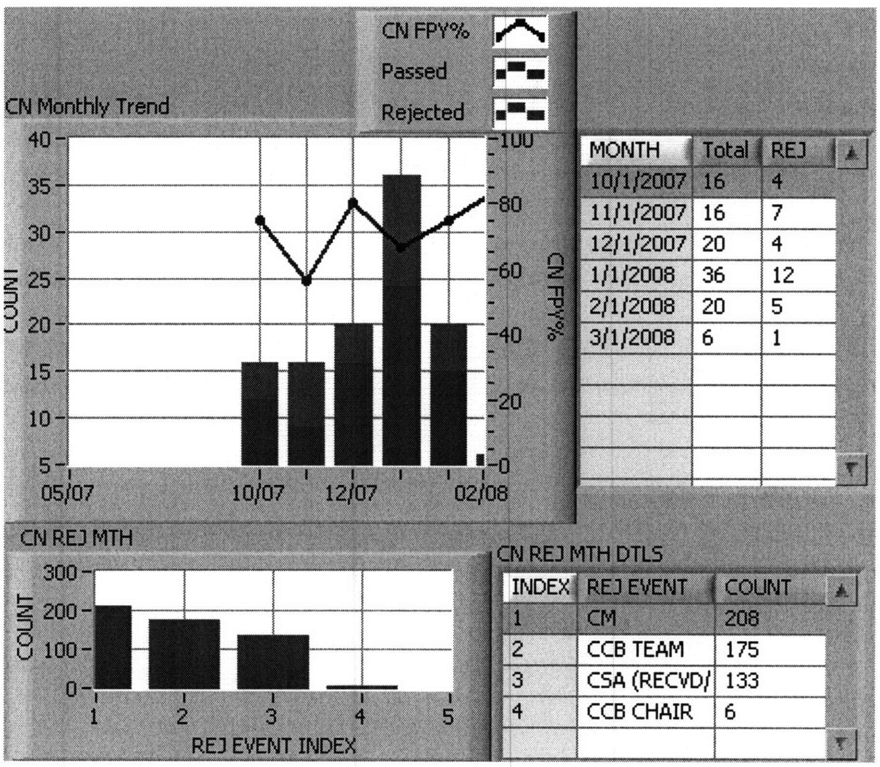


Figure 23. CN Approval, Rejection, and First-Pass Yield

4. <u>Engineering WIP (Aging of Open/Unresolved Defect):</u> The longer the WIP aged, the costlier it gets to fix. Thus, customers need to monitor WIP closely and to prevent it from aging. The red bars in the upper graph in Figure 24 show the quantities of engineering WIP initiated in that particular month but are still

unresolved today. The lower graph is a histogram of the same engineering WIP information. It shows that there are 12.5% of WIP over 90 day old.

5. Cycle Time Reduction and CN Workflow Tracking: Long cycle time is one of the most stubborn forms of waste. The author believed it can be tackled at the CN workflow level, as CN workflow is separated into multiple traceable steps, starting from the Assigned step where an engineer filled out a CN until the CM manager approves it. Then the Configuration Control Board (CCB) Team (usually consists of about 10 people as shown in Figure 26) has to individually review and approve the CN. Finally, the CCB Chairman will stamp the CN. Figure 25 shows the CCB Team took on average 19.7 days to approve a CN but the CCB Chairman needed about 13 days. While it will be ideal to shorten both cycle times, the true bottleneck might be the CCB Chairman. Thus, understanding his delay might be more essential. Furthermore, parallelizing and shortening the individual CCB team member lead time is also important. Thus, this dashboard makes the CCB team members responsible for their own delay by publicized the information.

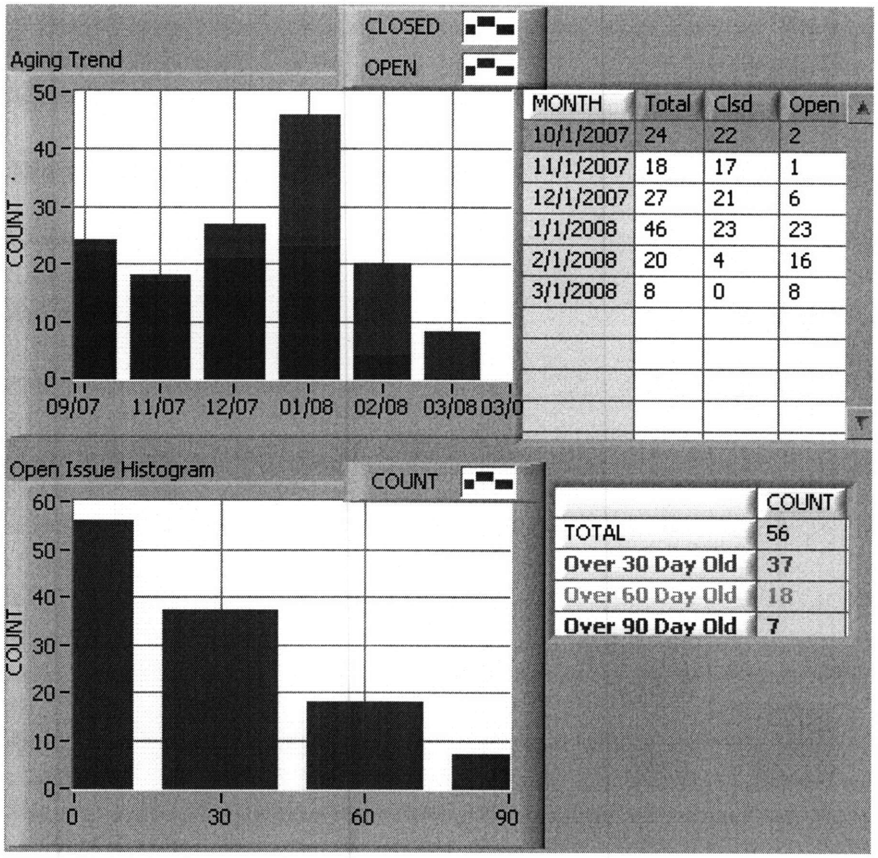
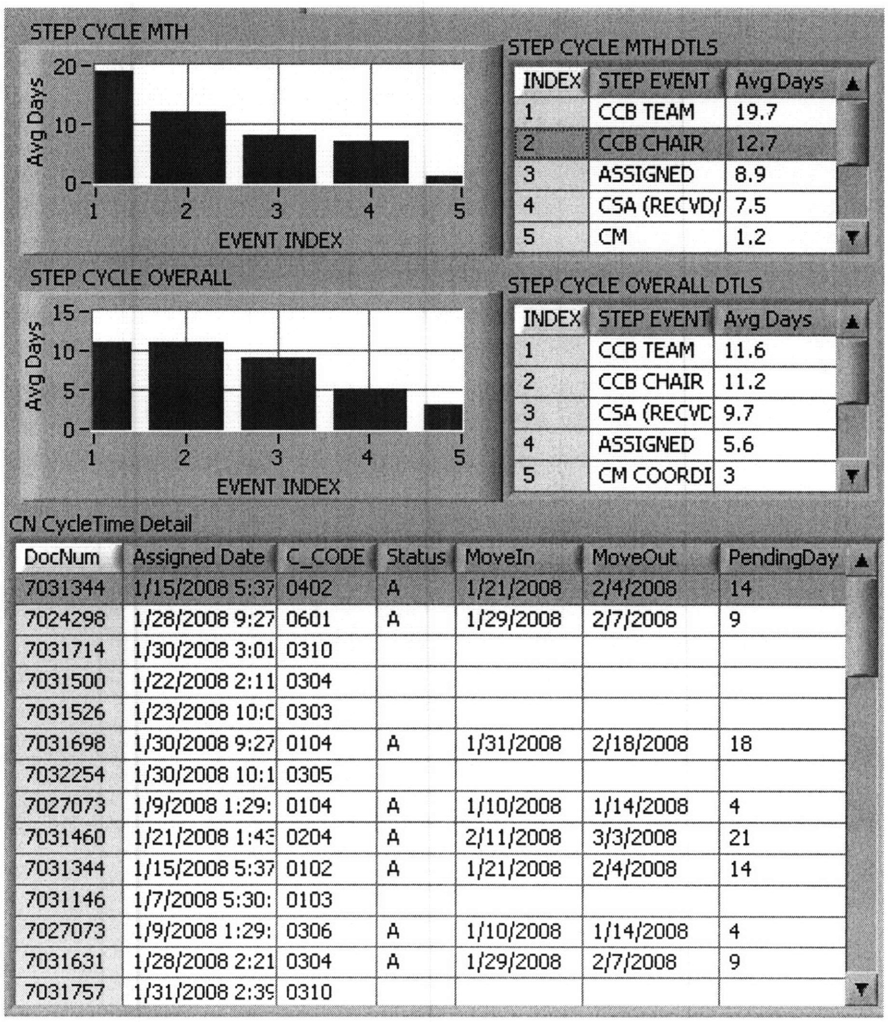


Figure 24. Engineering WIP

6. <u>Parts/Documents Rework Tracking:</u> Given the CN count vs. defect count issues discussed in Section 4.1.2, the author believed that counting the number of reworked parts/documents might be a more accurate count of the true number of defects. Figure 27 shows the rework part/document list in a particular period of time. For example, Figure 27 shows how a particular engineering unit buckets its parts/documents. The names with "-K" are the documents, which they do not count against their cost. The names with "60701" are parts from suppliers, which they do not count against their cost. The rest are the real physical parts built in-house and only these parts are counted against their cost.

7. Rework Cost Tracking: Finally, since each rework part/document has a cost associated with it, the ultimate goal is to track down the rework cost associated with each CN. The reason that this item is on the bottom of the prioritization list is mentioned in Section 4.1.2, the linkage of CN and rework cost is broken in the database. However, an approach to connect CN's to manufacturing rework has been identified and will be implemented. This will be done by linking the Shop Floor Data Management (SFDM) transaction to the ECN database as manufacturing transactions are posted on the floor.



STEP CYCLE MTH DTLS

INDEX	STEP EVENT	Avg Days
1	CCB TEAM	19.7
2	CCB CHAIR	12.7
3	ASSIGNED	8.9
4	CSA (RECVD/	7.5
5	CM	1.2

STEP CYCLE OVERALL DTLS

INDEX	STEP EVENT	Avg Days
1	CCB TEAM	11.6
2	CCB CHAIR	11.2
3	CSA (RECVC	9.7
4	ASSIGNED	5.6
5	CM COORDI	3

CN CycleTime Detail

DocNum	Assigned Date	C_CODE	Status	MoveIn	MoveOut	PendingDay
7031344	1/15/2008 5:37	0402	A	1/21/2008	2/4/2008	14
7024298	1/28/2008 9:27	0601	A	1/29/2008	2/7/2008	9
7031714	1/30/2008 3:01	0310				
7031500	1/22/2008 2:11	0304				
7031526	1/23/2008 10:0	0303				
7031698	1/30/2008 9:27	0104	A	1/31/2008	2/18/2008	18
7032254	1/30/2008 10:1	0305				
7027073	1/9/2008 1:29:	0104	A	1/10/2008	1/14/2008	4
7031460	1/21/2008 1:43	0204	A	2/11/2008	3/3/2008	21
7031344	1/15/2008 5:37	0102	A	1/21/2008	2/4/2008	14
7031146	1/7/2008 5:30:	0103				
7027073	1/9/2008 1:29:	0306	A	1/10/2008	1/14/2008	4
7031631	1/28/2008 2:21	0304	A	1/29/2008	2/7/2008	9
7031757	1/31/2008 2:39	0310				

Figure 25. Cycle Time Analysis

Routing and Approval Summary

Role	Yes/No	Date Processed
Originator ([redacted]) Submitted	Yes	12/19/2007
CM ([redacted] Reviewed) 22689	Yes	12/19/2007
CCB Team		
[redacted] Materials Engineer	Yes	12-19-2007
[redacted] Parts Engineering	Yes	12/20/2007
[redacted] Quality	Yes	12/20/2007
[redacted] Manufacturing	Yes	12/20/2007
[redacted] ISC	Yes	01/02/2008
[redacted] Logistics	Yes	12/19/2007
[redacted] Safety	Yes	12/21/2007
[redacted] Systems Engineer	Yes	12/19/2007
[redacted] SVTAD	Yes	12/19/2007
[redacted] Logistics	Yes	01/02/2008
[redacted] Manufacturing Product Engineering	Yes	12/20/2007
CCB Chairman ([redacted]) Approved	Yes	01/02/2008
AD Closed	Yes	01/10/2008

Figure 26. CCB Team Approval Routine

Parts Table

CN Doc Number	Parts
7031344	60701A1421
7031344	60701A3500
7031344	60701C1001
7031344	60701C1002
7031344	60701C1010
7031344	60701C1012
7031344	60701C1013
7031344	60701C1018
7031344	60701C1020
7031344	60701C1021
7031344	60701C1026
7031344	60701E2110
7031344	60701E2120
7031344	60701E2130
7031344	60701E2140

Parts Type

	Count
-K	1
60701	50
Others	61

Figure 27. Rework Parts/Documents

The lesson learned in this chapter is that customers' need is the basis of prioritization. In order to understand customer needs, one has to do Gemba walks: go see and go talk to customers directly. It is also important to understand the rationale of different business processes and make sure that everyone's voice is heard. This can help to consolidate improvement opportunities and eliminate duplicate ideas. As a result, everyone can work towards a major goal. VBS can help to make this change and to achieve customers' goals.

6 Improve – "Design and Implement Improvements"

To change and to improve are two different things.

German proverb

The fifth step of the Raytheon Six Sigma wheel is **Improve**. In this step, the to-be (ideal) state of data collection, data interpretation, and performance metrics were described. The author's recommendations on how this new VBS dashboard can help in solving the undesirable effects of the as-is state were discussed. The Kaizen continuous improvement activities and customers' feedback of the ECN dashboard development were also illustrated.

6.1 New Performance Metrics and Problem Solving Methodologies

In contrast to the as-is state described in Section 4.1, the ECN dashboard developed by the author provides **many different functionalities**. Its dynamic displays of multiple quality control and performance metrics and its **"drill-down" analysis capability** on defect and engineering WIP, CN first-pass yields, cycle time, and rework cost can help to change **problem solving behavior from reactive to proactive**.

Not only is the data available in real-time, VBS dashboards are also displayed on flat screen panels mounted throughout the factory floor (in Figure 2) and in this case, the dashboards will be displayed inside the engineering labs. The purpose of this **extensive and public deployment** of VBS all over public locations is to allow problems to be exposed to the public (everyone on the floor, including the visiting customers, can see the problems). Thousands more PC's on engineers' desks will have the ECN dashboard installed in the near future. As a result, this ripple effect created by VBS can significantly **change the corporate culture from privatizing to publicizing the data** as it has been observed in manufacturing operations. In addition, issues are exposed in earlier stages before they cascade and snowball into later stages; issues can also be predicted with real-time data analysis capability. These changes can help **coupling people's responsibility to their actions** and eventually **reduced rework cost and drive up Lean behavior**.

VBS also results in significantly shorter lead times (days to weeks instead of months to quarters) than traditional development methods. VBS is perceived as the "**disruptive technology**"[10] within Raytheon thanks to the disciplined common code and modularity software architecture. This provides VBS with the capability of exceptionally **quick turnaround** on deliverables, and thus the author can experiment many different ideas with lead time within days and show new/improved ideas to customers. This further enhances the leader-follower relationship described in Section 3.2.

Last but not least, VBS provides a **one-stop shop** for engineers and their management to view and analyze quality control and performance data. VBS networks the enterprise together on the division level and on the data level as shown in Figure 28. Therefore, VBS **eliminates a lot of non-value added work** for processing and fetching data from different sources. VBS establishes a discipline and ties the loose-ends of the disparate corporate. "The more discipline, the more freedom." VBS returns a lot of free time to employees through standardization.

6.2 Recommendations

Given the inherent disconnect between collecting and using data, **data collection is the fundamental issue that needs to be fixed**. Thus, the first improvement that the author recommended is to **re-design the CN Form** (the source of data collection). Specifically, the two separated tables in page 2 of the CN (as shown in Figure 17) have to be combined into one long table as shown in Figure 19. In this case, engineers will be able to input all information: the document or part requires rework (in column 12), the root cause (in column 20b), the reason for change (in column 20a), and the phase of origination in (column 20c), in one nice long row. In addition, constraints have to be added to force engineers to fill out all these fields: root cause, reason for change, and originated phase, in order to match 1-to-1 with each part/document entered. This improvement will eliminate the illusion that information in these 2 tables is disparate. It will also eliminate the ambiguity in counting the number of defects as this quantity is equal to the total number of rows, which is the same as the total number of parts/documents entered or the total number of root causes entered.

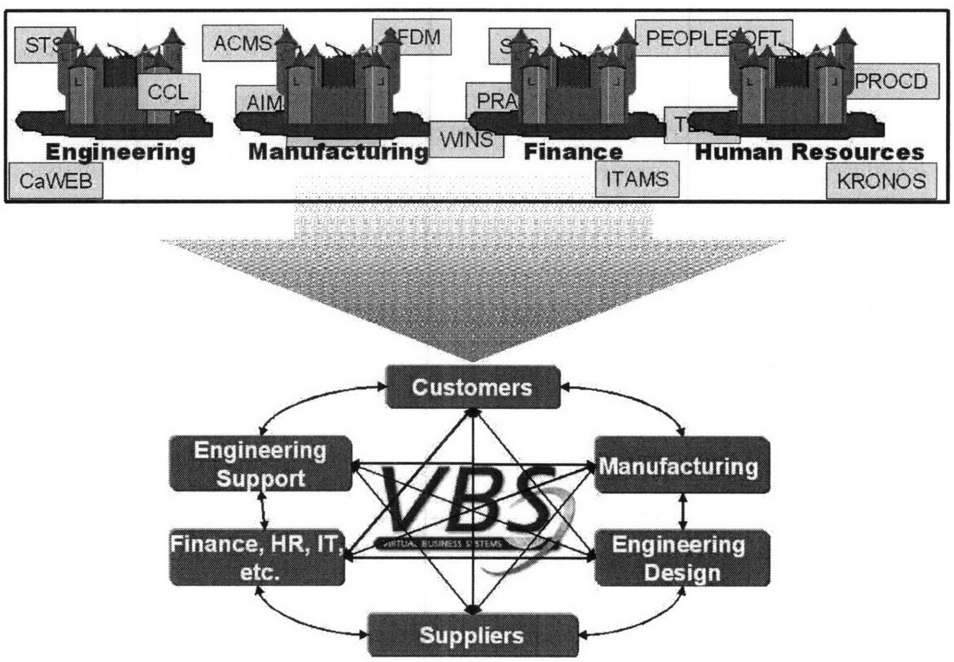


Figure 28. From "Silos" to "Network"

Along these lines, this improvement can also lead to the distinction of good CN's from bad CN's, as each rework part/document is now accountable by the cause code, which is the key to identify defect from non-defect. However, the current non-defect cause codes are still ambiguous as they do not necessarily represent improvements. Thus, new cause codes emphasized on improvement need to be added. While this involves corporate IT to define new business processes, the author's recommendation will be discussed in the review and redesign planning by the end of this year.

Furthermore, engineers need more varieties of cause codes for documenting defects and improvements, such that they do not have to use "not applicable" as much as they do now. Again, this involves corporate IT's approval and from the Fishbone Diagram shown in Figure 20, we know this variable is a constant. While reporting and displaying the "not applicable" issues will influence the absolute number of defect count, these items do not add any values to root cause analysis and thus, the author chose to ignore them for now.

As for the dilemma of standardizing or customizing for each engineering unit, the author strongly believed that metrics drive behavior but not the other way around. Thus, while the VBS dashboard is designed to provide a standardized data collection and analysis platform for all engineering units, VBS also gives flexibility to each unit for manipulating the data as all charts and tables in VBS are downloadable.

Another improvement recommended by the author is to **incorporate finance information into CN data collection**. As mentioned in Section 4.1.2, rework parts are documented in CN's and thus stored in the engineering database but rework hours and cost associated with the rework part are stored in the database administered by the Finance division. As mentioned in Section 4.1.2, a process has been identified to link manufacturing rework directly to ECN database and will be implemented. But for now, a simple fix can be done in re-designing the CN form. For example, an extra column can be added to the table (shown in Figure 19) for inputting the estimated rework hours.

6.3 Kaizen, Iterations, and Feedback

The design and implementation of this ECN dashboard for engineering units went through five major iterations as shown in Figure 30, Figure 31, Figure 32, Figure 33, and Figure 34. This Kaizen continuous improvement process is based on the Method of Successive Approximations[38] and the rapid convergence of deliverables was all driven by customers' and end-users' feedback. The implementation lead time of each iteration was about a week and feedback from customers and end-users was collected immediately within the next week.

6.3.1 First Iteration

Figure 30 shows the summary page of the first version. This first version is meant to be a quick proof-of-concept based on the ideas and insights from the mentor of this project and a quick prototype of how this VBS dashboard uses the web-based system as the baseline of its design. Even though this prototype was developed from scratch by the author, given the common code modules, it only took about a week to develop and it was already 50% towards the goal (as shown in Figure 29).

Both the mentor and the author believed that the defect and aging metrics reported in the web-based system is useful to the engineering community so this VBS dashboard has to provide at least these functionalities. Thus, this version looked awfully similar to the web-based system, with the additional function of root cause Pareto analysis in the upper left corner. This version shows the defect data of all engineering units as a whole. It also has the capability to view the defect details as shown in Figure 16.

---

[38] Also known as the Picard iteration, developed by Charles Emile Picard (1856-1941).

6.3.2 Second Iteration

Figure 31 shows the summary page of the second version. After the first version was reviewed by everyone in the VBS core team, the author's supervisor suggested some bug fixing and cosmetic changes. In addition, the author and the supervisor had strategized on how to make this VBS dashboard more applicable to the end-users (engineers) in each individual engineering unit, since the dashboard will not only be used by the upper engineering management. Thus, the author added the engineering unit selection pull-down menu at the top left corner. End-users from a particular engineering unit can now view their data. However, the beauty of the system is to change the data collection culture from privatize to publicize and to couple people's actions to responsibilities, so end-users can still see other engineering units' data on the dashboard if they choose to.

At this stage, the dashboard was already 70% of success (as shown in Figure 29). The author and the supervisor were confident and felt ready to show the sponsors from engineering quality this new VBS dashboard for review.

6.3.3 Third Iteration

Figure 32 shows the summary page of the third version. The author led a number of review sessions with the quality control division. The recommendations and major improvements came out of these reviews were the addition of CN metrics and the relocation of some lower level metrics (e.g. the phase matrix by cause code, which is the smaller matrix in the upper right corner) from the summary page to the details page, since these metrics will only be needed for "drill-down" purposes.

CN metrics included the total number of CN's filed per month, the total rejected CN's per month, and the CN first-pass yield. The author worked with engineering quality to define these metrics and helped them to understand the difference between CN count and defect count as described in Section 4.1.2. They were quite confused at this stage as every quantity on the dashboard was in defect count except for the table and the bar graph in the left bottom corner are in CN count. They were not very used to the difference at the beginning but after several iterations of explanation and experimenting, they decided to keep the CN metrics as they are conventions within engineering quality but they also believed the defect metrics make sense and decided to use them as well.

In addition, the engineering continuous improvement division also had a discussion with the author about adding cycle time metrics, as engineering units have burning needs in driving down cycle time. This iteration marked 83% of success (as shown in Figure 29).

6.3.4 Fourth Iteration

Figure 33 shows the summary page of the fourth version. The investigation and discovery process in this iteration contributed greatly to customer satisfaction. The author organized a large-scale review session and engaged the input and feedback from all customers as well as end-users (engineers) within the engineering community. This iteration was a real breakthrough stage in both technical and leadership engagement and it was 90% towards the goal (as shown in Figure 29).

In terms of technical engagement, engineers expressed their immediate need of driving down cycle time. Thus, the author designed a few "drill-down" capabilities focusing on analyzing the lead time and the frequency of rejections at each CN approval step. These cycle time metrics can help engineers to track down which personnel or organization is the bottleneck in the CN approval process.

Furthermore, the author also worked closely with the sponsors on designing the table in the left bottom corner. This table did a great job in sorting and compartmenting the defect metrics and the CN metrics. The entire table is clickable and is driving the displays on the right hand side of the dashboard. The right hand side of the dashboard consists of six tabs shown in Figure 34. These tabs are displayed based on the following selections:

1. On launching: the overall root cause Pareto analysis is displayed as shown in Figure 33. The Pareto chart is clickable and will show the details of the selected defect as shown in Figure 16.
2. Total Defects column: the root cause Pareto analysis of the corresponding month is displayed, in the same format as shown in Figure 33. Again, the Pareto chart is clickable and will show the details of the selected defect (as in Figure 16) based on the selected month.
3. Closed/Open Defects column: the engineering WIP (aging issue) tab as in Figure 24 is displayed. The tables are clickable and will show the details of the open/closed/total defects of the selected month in the same format as in Figure 16. The graph in the bottom is the histogram representation of the open defects.
4. Total CN column: the cycle time tab as in Figure 25 is displayed. It shows the average cycle time of each CN approval step. The 2 upper tables are clickable and will drive the table below to show details. This table is also clickable and will open the CN details tab as shown in Figure 35 for "drill-down" analysis. Users can see at which step the CN

was rejected and how long it took to process the approval at each step. Users also have the option to click the button on top right corner to view the actual CN, which will eventually lead to the page shown in Figure 26, for the personnel responsible for the CN approvals at each step.

5. Rejected CN's and First-Pass Yield column: the tab as in Figure 23 is displayed. The graph above is pretty self explanatory, while the chart below shows the steps which experienced rejections the most.

6. Phase Matrix: the cells in the phase matrix (in Figure 21) are also clickable. They will bring up the tab of the selected originated phase/detected phase in the Pareto chart format.

6.3.5 Fifth Iteration

Figure 34 shows the summary page of the fifth version. This iteration seems to be the destination but the Kaizen continuous improvement activity is really a journey. The dashboard was 95% towards the goal (as shown in Figure 29) and was deployed in one of the "quick turnaround" engineering units at this stage. The author worked directly with the engineers (end-users) to create a dashboard that is useful to them. They suggested that part counting is important because they plan the budget around reworked parts. That is the reason the author added an extra column, "Parts", in the table and an extra tab on the right hand side (as shown in Figure 34).

In addition, the author also learned about the concept of non-defect cause codes and separated them from the existing defect counts. The non-defect issues are not necessarily defects but they are counted and documented in the CN's as well. Thus, the author added the pull-down menu on top of the phase matrix, which allows users to view based on "defect", "non-defect", or "both" counts.

The engineering quality division is very satisfied with this version and they are ready to deploy it into different engineering units. This dashboard focuses on hardware defects (issues) but the engineering quality division also needs to track defects in drawing documents so the next iteration will be to incorporate the drawing defects.

The most important lesson learned in Kaizen continuous improvement is brainstorming and building solutions together with customers. While this iteration is still not ideal, its design is rapidly converging on Raytheon's business goals. **Enterprise transformation is not a destination but is a journey**, thus, getting stakeholders' buy-in at every step is very important and the VBS development journey has taken this seriously.

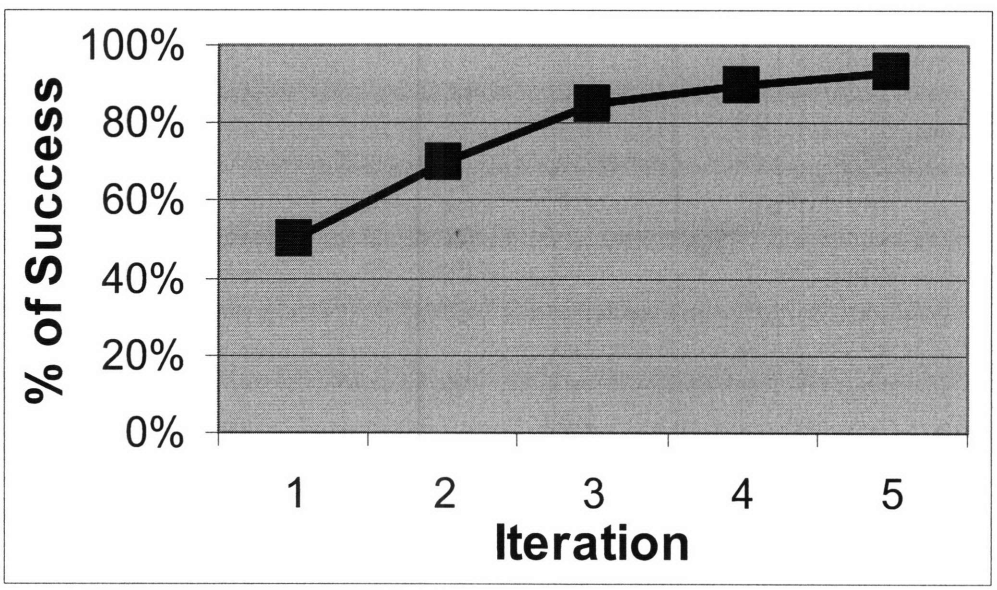


Figure 29. Rapid Prototyping Convergence Based on Method of Successive Approximations

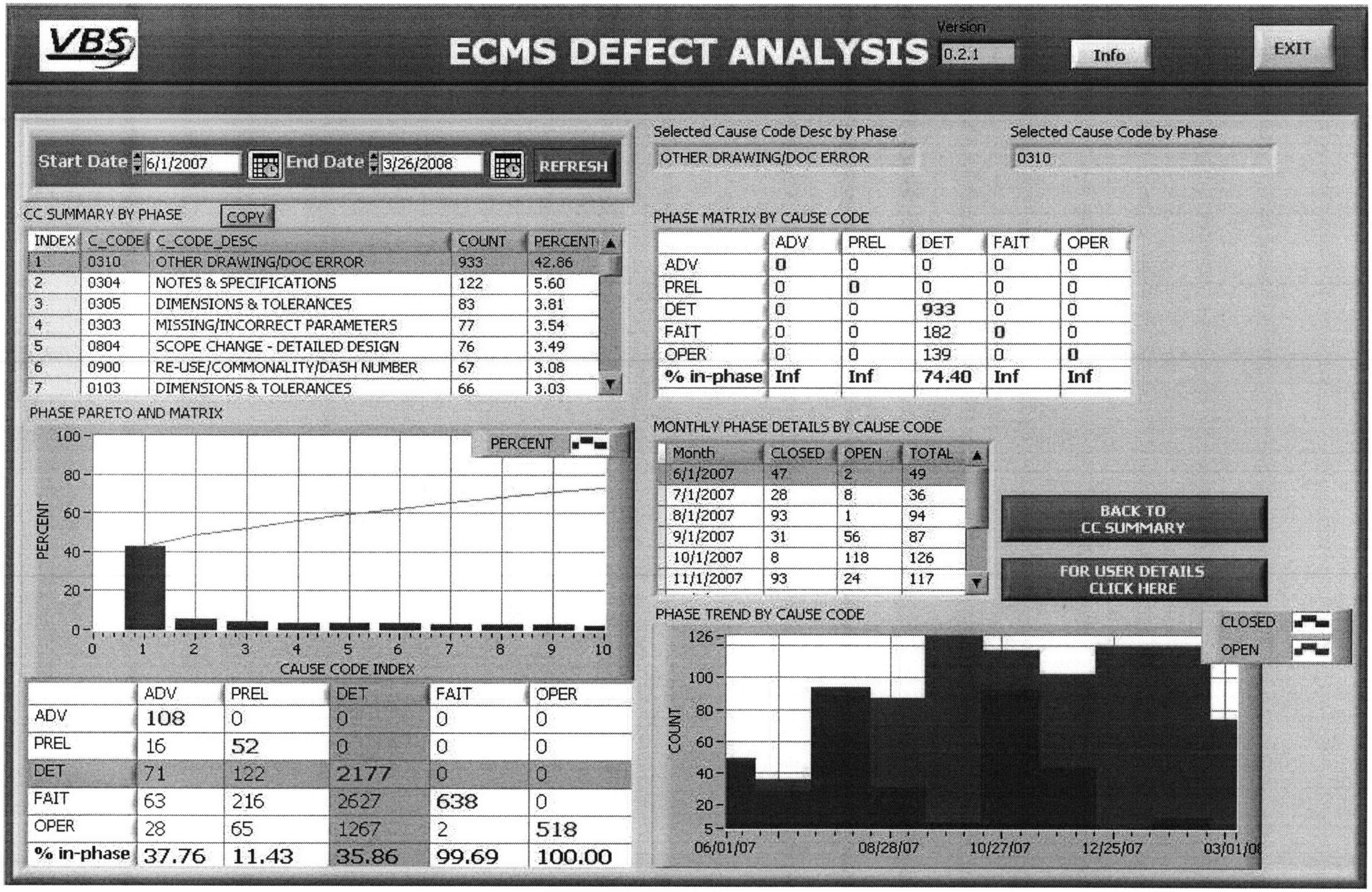


Figure 30. VBS Dashboard Main Screen: First Iteration

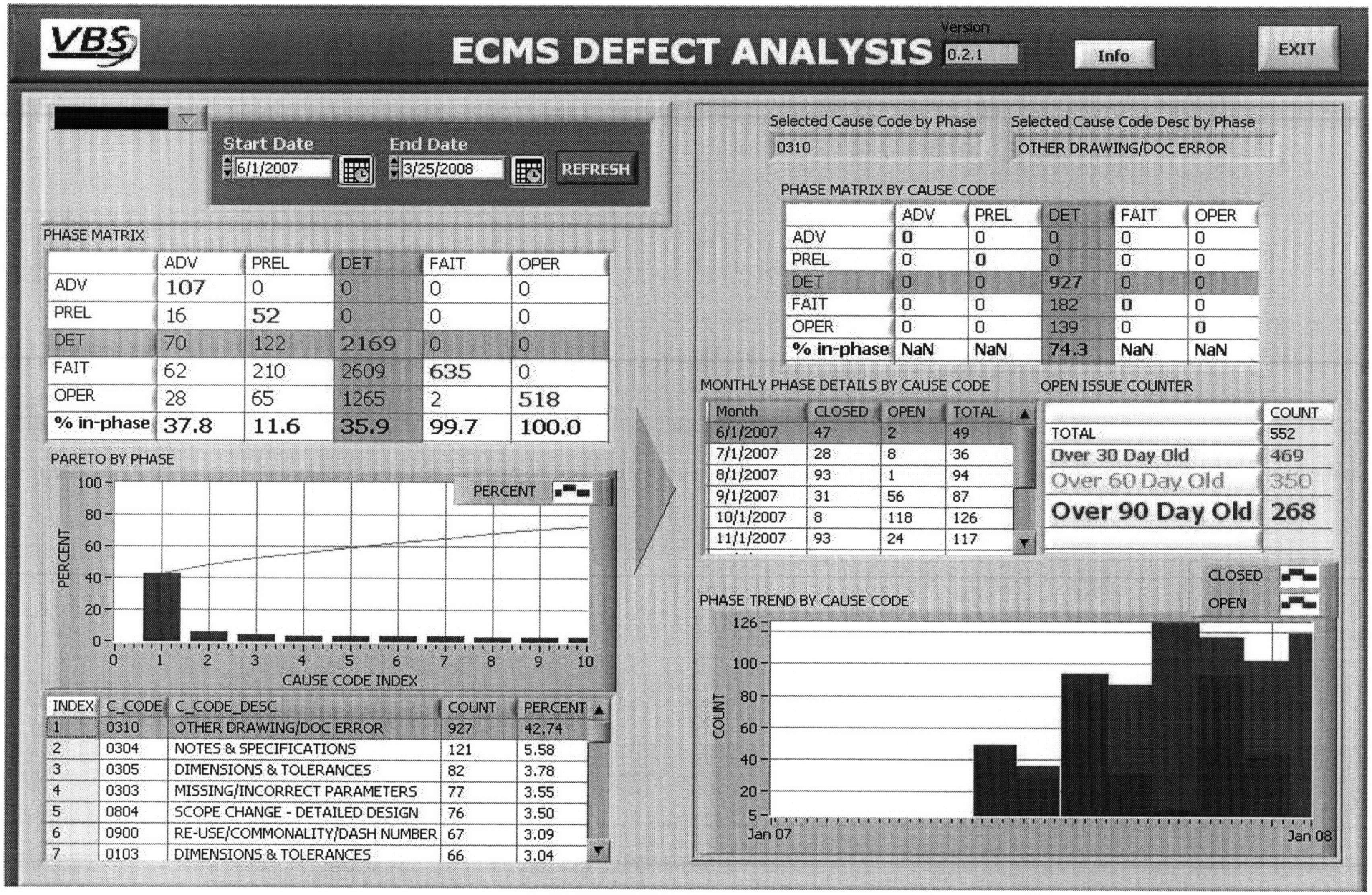


Figure 31. VBS Dashboard Main Screen: Second Iteration

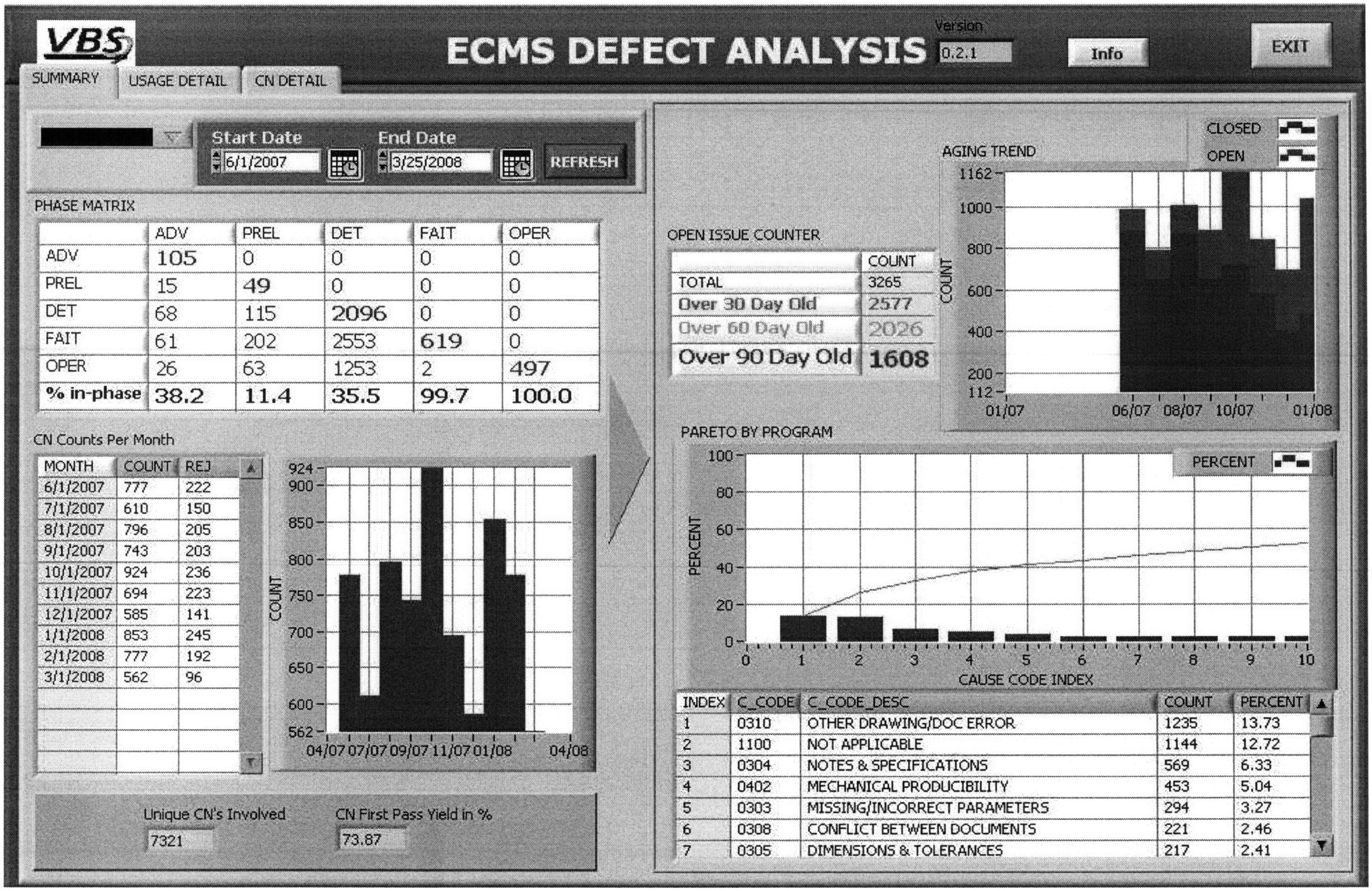


Figure 32. VBS Dashboard Main Screen: Third Iteration

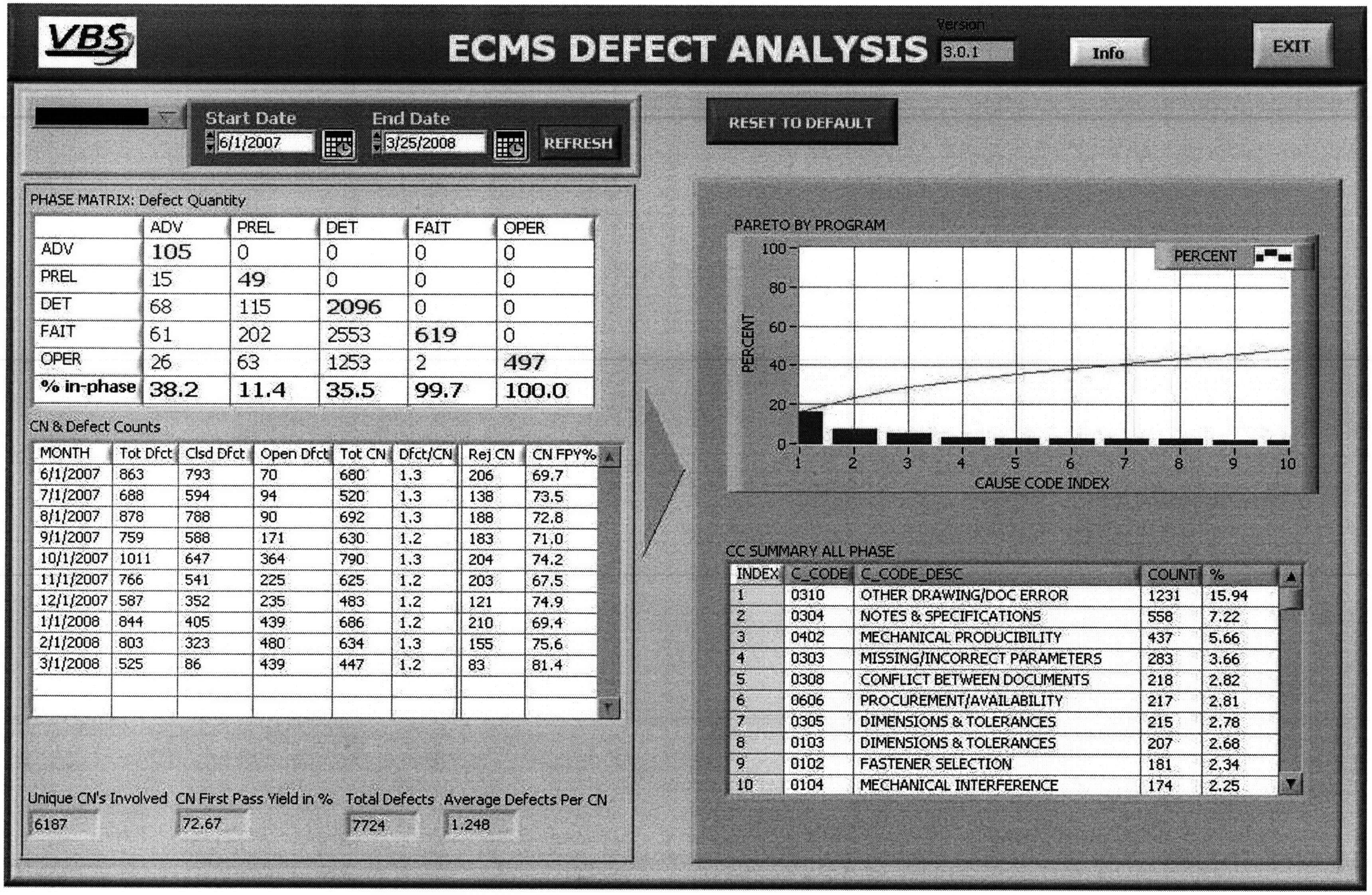


Figure 33. VBS Dashboard Main Screen: Fourth Iteration

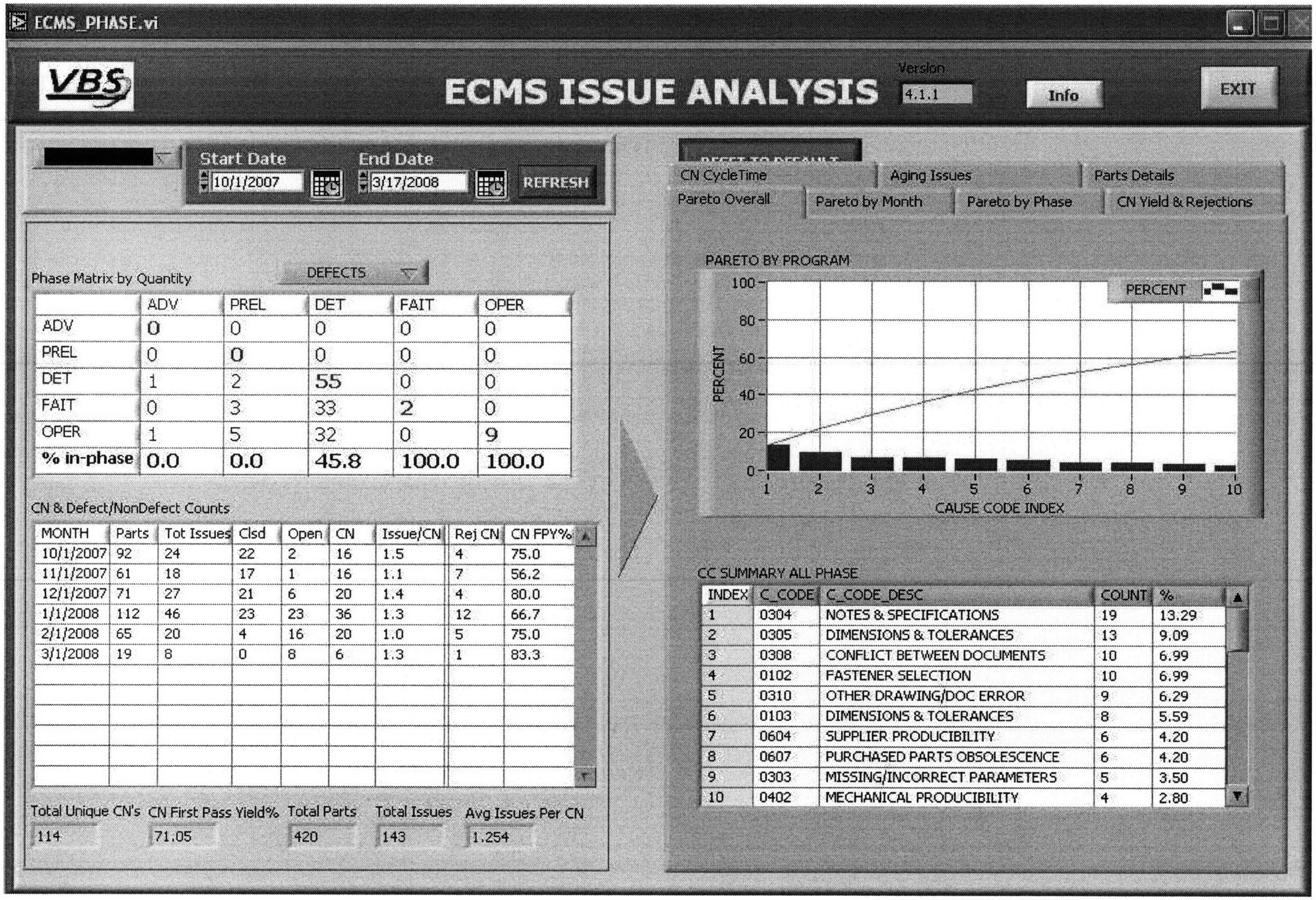
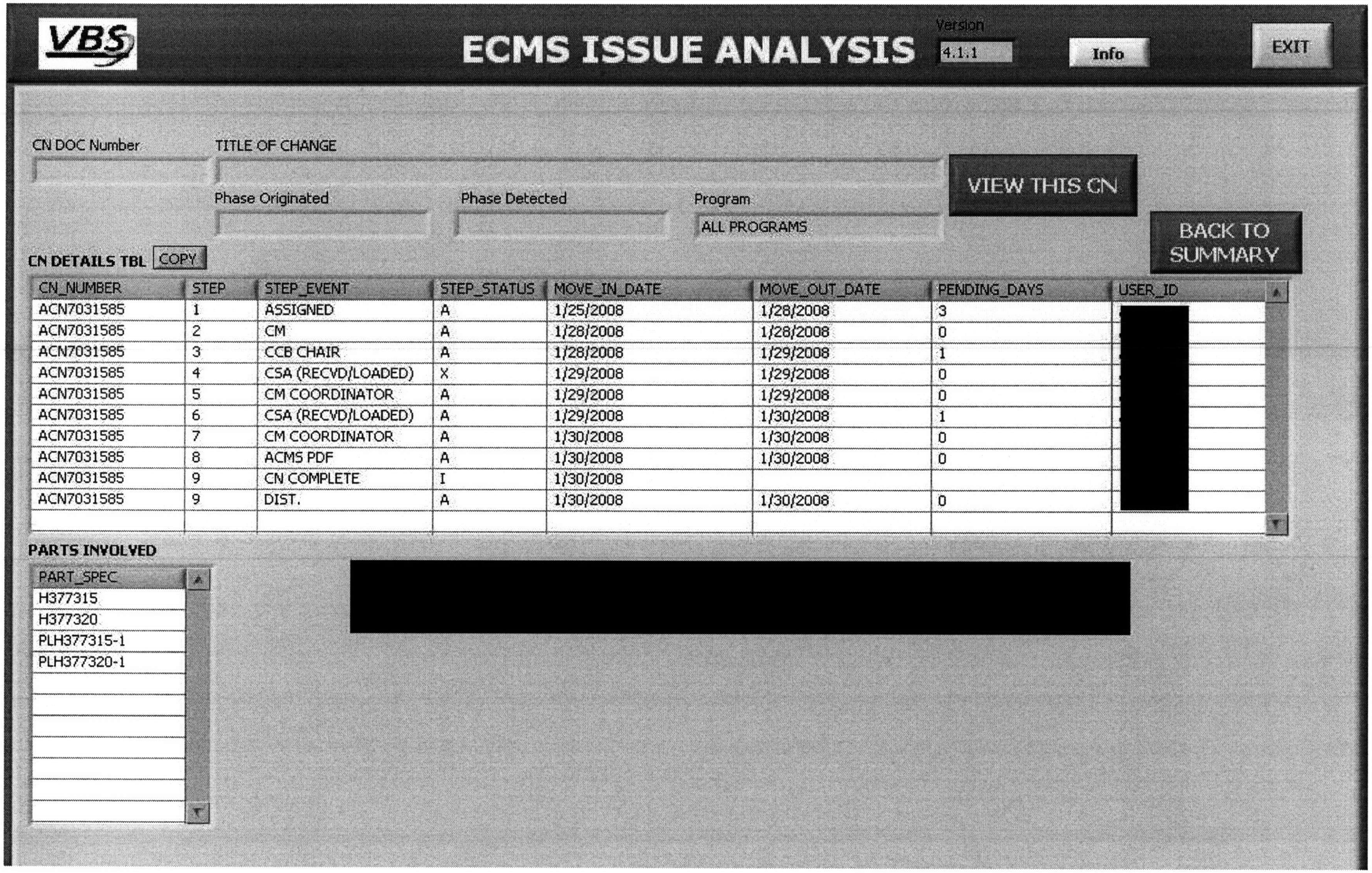


Figure 34. VBS Dashboard Main Screen: Fifth Iteration



CN_NUMBER	STEP	STEP_EVENT	STEP_STATUS	MOVE_IN_DATE	MOVE_OUT_DATE	PENDING_DAYS	USER_ID
ACN7031585	1	ASSIGNED	A	1/25/2008	1/28/2008	3	[redacted]
ACN7031585	2	CM	A	1/28/2008	1/28/2008	0	
ACN7031585	3	CCB CHAIR	A	1/28/2008	1/29/2008	1	
ACN7031585	4	CSA (RECVD/LOADED)	X	1/29/2008	1/29/2008	0	
ACN7031585	5	CM COORDINATOR	A	1/29/2008	1/29/2008	0	
ACN7031585	6	CSA (RECVD/LOADED)	A	1/29/2008	1/30/2008	1	
ACN7031585	7	CM COORDINATOR	A	1/30/2008	1/30/2008	0	
ACN7031585	8	ACMS PDF	A	1/30/2008	1/30/2008	0	
ACN7031585	9	CN COMPLETE	I	1/30/2008			
ACN7031585	9	DIST.	A	1/30/2008	1/30/2008	0	

PART_SPEC
H377315
H377320
PLH377315-1
PLH377320-1

Figure 35. CN Details Tab

7 Achieve – "Celebrate Achievements and Build for Tomorrow"

However beautiful the strategy, you should occasionally look at the results.
– *Winston Churchill*

The sixth (but not the final) and most exciting step of the Raytheon Six Sigma wheel is **Achieve.** In this step, the physical and financial benefits of this VBS dashboard to Raytheon were documented. Author's contributions and lessons learned from this internship were also discussed.

7.1 Fulfillment of the Author's Expected Contributions

The transformation from the as-is state to the to-be state is the road to operational excellence. The VBS dashboard that the author developed leverages previous VBS success in manufacturing deployment and naturally extends to the engineering community. This dashboard provides a complete and comprehensive reporting and root cause "drill-down" analysis system for all Raytheon IDS' engineering units. The overall achievement can be summarized by the process cycle of this new VBS dashboard as shown in Figure 37.

Reiterating the expected contribution in Section 1.4, the author had successfully designed, developed and implemented a new VBS dashboard from scratch (sample programming code is shown in Appendix: Figure 38, Figure 39, and Figure 40) for engineering design and support units based on customer requirements. The author completed the investigation of the current data collection and data interpretation methodologies in quality control and performance assessment through the development of this VBS dashboard and customer interaction. The author also provided recommendation to Raytheon IDS on new data collection processes and well-defined quality control and performance metrics. This new VBS dashboard can introduce around $5M of cost savings (described below) in cycle time, rework, and engineering defects.

The new VBS dashboard provides many different functionalities for quality control and performance assessment over the web-based system in the as-is state. Over the course of developing this new dashboard, the author also helped to sharpen and re-defined some definitions of quality control and performance metrics. VBS not only provides the quality control metrics: the defect counting, engineering WIP, as well as the CN quantity, approval, rejections, and first-pass yield, it also provides the cycle time analysis for Shingo's continuous improvement assessment. Both upper management and engineers can use this dashboard to start realizing continuous involvement. They can determine what types of CN's they should be attacking and what types of defects should be avoided from happening.

This VBS dashboard is not only a reporting system, it also has the root cause "drill-down" analysis capability. The dynamic "drill-down" analysis capability uses real-time data to identify and solve problems as they occur, not after the damage is done. The data is active and comes after you, not to be viewed at leisure. This can lead to defect prevention and change the problem solving attitude from reactive to proactive.

Like other VBS dashboards, this new VBS dashboard will also be massively deployed in public locations. This propaganda idea allows information to spread widely and rapidly to the public. Thus, VBS helps to change the data ownership from privatize to publicize. In addition, making data available to the public can drive people's behavior, as people's actions are now coupled with their responsibilities. This further drives up the Lean behavior on an individual level.

This dashboard also provides a one-stop shop for data collection and analysis. VBS eliminates the non-value added work for processing and fetching data from multiple sources and divisions. VBS links up disparate divisions and databases such that cross-division metrics, such as rework cost, can be tracked.

Last but not least, VBS dashboards build on modular software architecture. VBS' "common code" building blocks allow rapid prototyping and experimenting on new concepts and thus, enable quick turnaround on deliverables. This capability also allows this new VBS dashboard to quickly penetrate into the engineering community. Ultimately, VBS provides a platform for everyone to watch how individuals take actions to drive down the number of CN's, the percentage of out-of-phase defects, and the duration of cycle time.

In terms of **personal achievement**, the author was awarded the **Raytheon Six Sigma Specialist** title by the project sponsor and supervisor for the success of this project.

7.2 Financial Benefits

In general, VBS helped Raytheon's manufacturing facilities to generate bottom-line savings of $46M in 2005, $49M in 2006, and $50M in 2007, compared to the net income of $871M, $1.3B, and $2.6B in these years respectively.

Furthermore, VBS is an extremely Lean organization running on a small budget, with funding at least one magnitude lower (thousands vs. millions) than that of corporate IT and with only two major employees running the show. Currently, my team is working with other business segments (e.g. manufacturing facilities in Tucson, AZ) described in Section 1.5 and gradually spreading and penetrating VBS all over Raytheon.

7.2.1 NPV Analysis on Rework Labor Cost Savings

The new VBS dashboard that the author developed in this thesis has a return on investment (ROI) of over 6 times. Figure 36 shows the detailed NPV analysis based on rework labor cost savings.

Referring to Section 2.3, VBS provides cost savings via two major dimensions:

1. Revealing problems ahead of time (driving down number of CN's and out-of-phase defects)
2. Returning some free hours to employees (driving down cycle time and data fetching/processing hours)

Change notifications introduced about 10% of in-house (as opposed to rework at suppliers') rework hours on parts at IDS. The associated support hours (the hours spent to support any rework activities, included procurement, supply chain management, inspection, administration, etc.) were about 15% of the in-house rework hours.

Given that Raytheon IDS can achieve on average 8% of rework cost savings annually based on business process improvement, the conservative estimate of the extra cost savings provided by this new VBS dashboard can at least double this natural savings. Based on these statistics, the author computed an NPV analysis on rework and support hours over the next 5 years and assumed not further improvement in cost savings thereafter. **The NPV[39] on rework labor cost savings is $5.3M**. Given the $80K of the author's internship cost, this investment is well over 6X.

---

[39] Assumptions (information from Reuter): Risk of this project is similar to the risk of the enterprise. Equity value = $25.4B, which is $59.5 (average stock price of 2007) x 426.2M outstanding shares; Debt value = $2.3B (long term book debt in 2007), Beta = 0.48, Return on equity = 6.36% based on CAPM using a risk free rate = 3% (10-year Treasury note), market premium = 7% (historic average), return on debt = 7% (based on Moody's rating), effective tax rate = 30%, and thus, WACC = 6.24%.

7.3 Stakeholders' Satisfaction

The major stakeholder and sponsor of this project, Engineering Quality Control team, was very satisfied with the quality and turnaround time of the ECN dashboard. Given the big success, they are going to embed this dashboard as a major portion of the overall Raytheon IDS dashboard on Dan Smith's (the president of IDS) desktop.

Engineering Quality Control team is also going to deploy the author's ECN dashboard and to use this dashboard to establish a new standard in Engineering Review, a.k.a. the Team of X (which consists of upper management and engineers from individual engineering units) meetings. The engineering quality lead had assigned a dedicated champion to sponsor the ECN dashboard as the primary tool for Team of X meetings. This will result in a disciplined, efficient, and well monitored review process for the continuous improvement of the ECN process across all of IDS.

The Continuous Improvement team also helped the ECN dashboard to secure buy-in from a major "quick turnaround" product group and had started a pilot program in this engineering unit, in order to help them drive down cycle time and aging issues. In addition, the upper engineering management is also very interested in the cycle time and aging reduction capability of the ECN dashboard. All of these will help further deployment in different engineering units.

7.4 Next Step

This ECN dashboard captures hardware defects. However, drawing defects and software defects are also hurting Raytheon IDS' bottom-line performance. Thus, these two issues will be the next steps of VBS deployment in engineering.

7.4.1 Drawing Defects

Defects arise from engineering drawing releases require different sets of metrics, e.g. defect density – the number of drawing issues within a grid on the actual drawing. While drawing defects are also important to tackle, they are the next item on the priority roadmap and thus will not be discussed in this thesis.

7.4.2 Software Defects

Software defects are as important as hardware defects in engineering design. They are ranked after drawing defects because they have lower occurrence and thus are out of the scope of this thesis.

7.4.3 Supply Chain

Finally, as mentioned in Section 1.3, the author's successor is going to extend VBS outside the enterprise to the vendors. This project aligns directly to the enterprise transformation vision of VBS and naturally extends VBS upstream.

	2007	2008	2009	2010	2011	2012	Terminal Value
rewk hours	[redacted]						
support hours							
man-year							
new salary/yr	$						
orig rewk hrs							
orig man-year							
orig salary/yr	$						
Saving in salary	$ -	$ 122,410	$ 215,441	$ 284,578	$ 334,364	$ 368,560	
Saving in labor hr	0	1548	2725	3600	4229	4662	
Cost	$ 80,000						
FCF	$ (80,000)	$ 122,410	$ 215,441	$ 284,578	$ 334,364	$ 368,560	$ 368,560
Discounted FCF	$ (80,000)	$ 115,220	$ 190,876	$ 237,321	$ 262,461	$ 272,311	$ 4,363,850.81
NPV	**$ 5,362,039**						

Figure 36. NPV Analysis on Rework Labor Cost

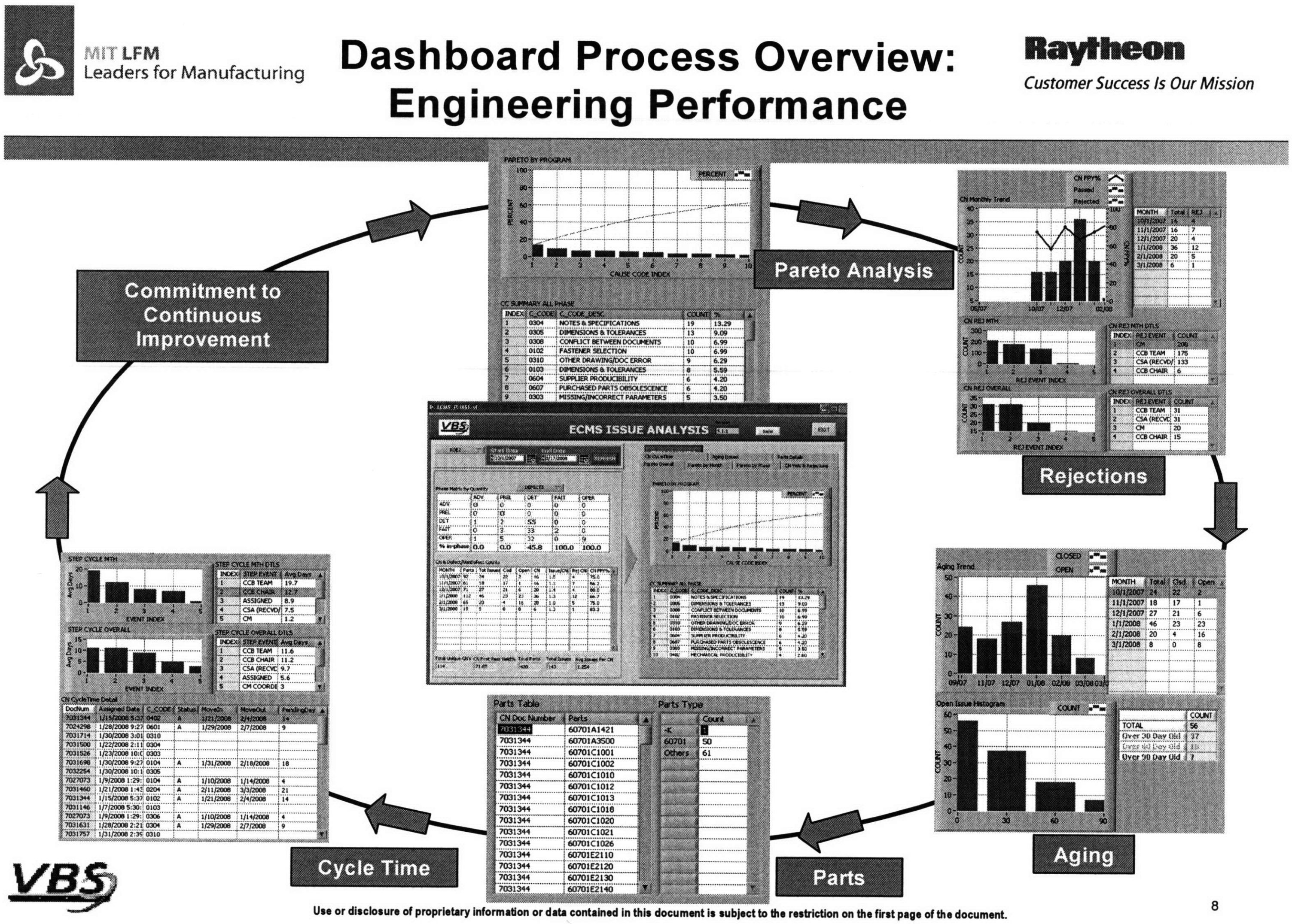


Figure 37. VBS Dashboard Process Cycle

7.5 Lessons Learned

Enterprise transformation is very challenging as there are a large number of degrees of freedom in an enterprise. These degrees of freedom can be thought of as employees, while their activities are driving the organizational entropy. There are also many activities competing for human resources each day, e.g. replying an email, making a phone call, delivering products to customers, etc. Some of these activities add value to the enterprise but many of them may have limited or no value added. Thus, there must be a systematic effort to bias employees' actions and continuously increase Lean behavior.

"To make an end is to make a beginning." [40] Similar to the Theory of Constraints[41], Lean transformation is not a destination but is a journey. Lean transformation requires multiple iterations of continuous improvement and VBS is meant to be the highway of Raytheon's Lean transformation journey which leads Raytheon to its operational excellence. However, given the political and cultural issues, VBS might seem to be "a mantis trying to stop a chariot[42]" at this point.

As every particle in the universe obeys Newton's Third Law, "To every action, there is an equal but opposite reaction". Lean transformation is never easy and over the course, there is definitely opposition and friction. This Ying-Yang relationship illustrates the idea: While data is a powerful tool to bias people to act according to Lean principles, a systematic data driven approach to operational excellence requires Lean data. Thus, as long as your result and argument is always driven by Lean data and statistical metrics, your contribution will always be sustainable.

[40] From T.S. Eliot, Four Quartets

[41] Eliyahu Goldratt: The Goal

[42] Chinse idiom: Dated back to late Zhou Dynasty, when the Emperor of Qi's chariot ran into a mantis trying to fight the chariot by holding it back, the emperor thought the insect was brave so he ordered his chariot to go around it. Today, however, people negate the original meaning of this idiom and use it to describe someone overrates oneself and tries to hold back an overwhelmingly superior force.

Last but not least, continuously acting to improve performance is essential. Mark Twain said, "Thunder is good, thunder is impressive, but it is the lightning that does the work.[43]" VBS eliminates the non-value added work and emphasizes on the value-added work. An enterprise can only be transformed when all the degrees of freedom are biased towards the same direction. I believe that Lean and Six Sigma principles together with statistical metrics are driving employees to march towards the enterprise's common business goal.

[43] From The Letters of Mark Twain

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Glossary

CMMI: CMMI is a process improvement approach originated from the Software Engineering Institute of Carnegie Mellon University. It has five levels of achievement: Initial, Managed, Defined, Quantitatively Managed, and Optimizing. It provides organizations with the essential elements of effective processes.

- Step 1 - Initial: Process is unpredictable, poorly controlled, and reactive.
- Step 2 - Managed: Process is characterized for projects and is often reactive.
- Step 3 - Defined: Process is characterized for the organization and is proactive.
- Step 4 - Quantitatively Managed: Process is measured and controlled.
- Step 5 - Optimizing: Focuses on process improvement.

VBS: Virtual Business System, a visual-based analytics and real-time information displaying system

LabView: A graphical programming software development tool produced by National Instruments

Shingo Award: Shingo Award is known as the Nobel Prize in Operational Excellence. It was named after Shigeo Shingo, a disciple of Taiichi Ohno.

R6σ: Raytheon Six Sigma is a knowledge-based process for transforming Raytheon's culture to maximize customer value and grow Raytheon's business.

CN: Change Notification (CN) is the form which engineers fill out when they discover an issue (defect or non-defect) and need to notify other related personnel for a change in part design, drawing, or other documents.

In-Phase Defect: In-phase defects are those defects originated and detected in the same engineering phase

Out-of-Phase Defect: Out-of-phase defects are those originated in an earlier phase but detected in a later phase.

Quick Turnaround Engineering Unit: These engineering units are on a different funding model compared to most of the defense contracts in the rest of the company. Thus, they usually need to finish projects within a few months as opposed to within a few years.

Appendix

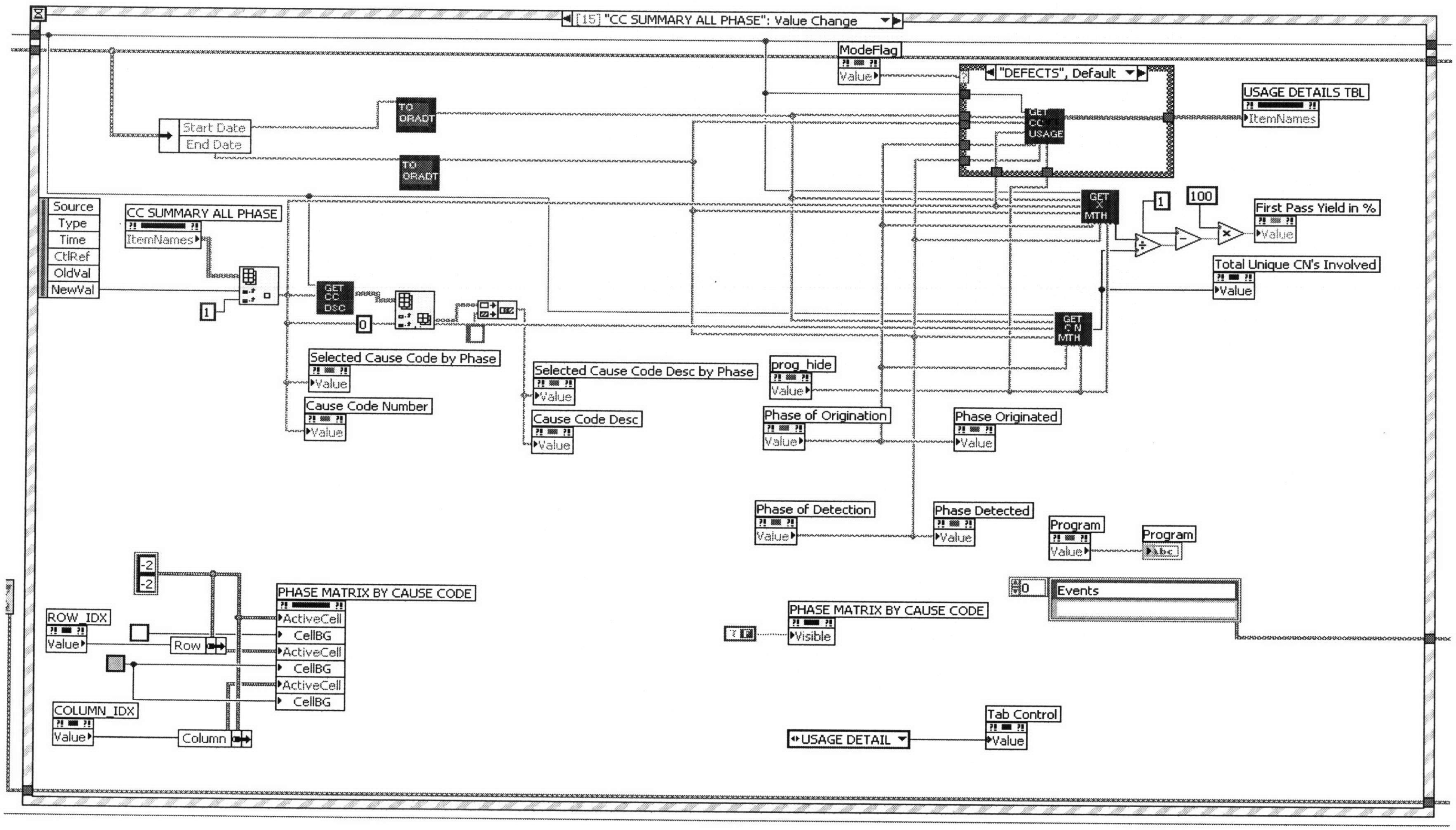

Figure 38. Sample VBS Dashboard LabView Development Code

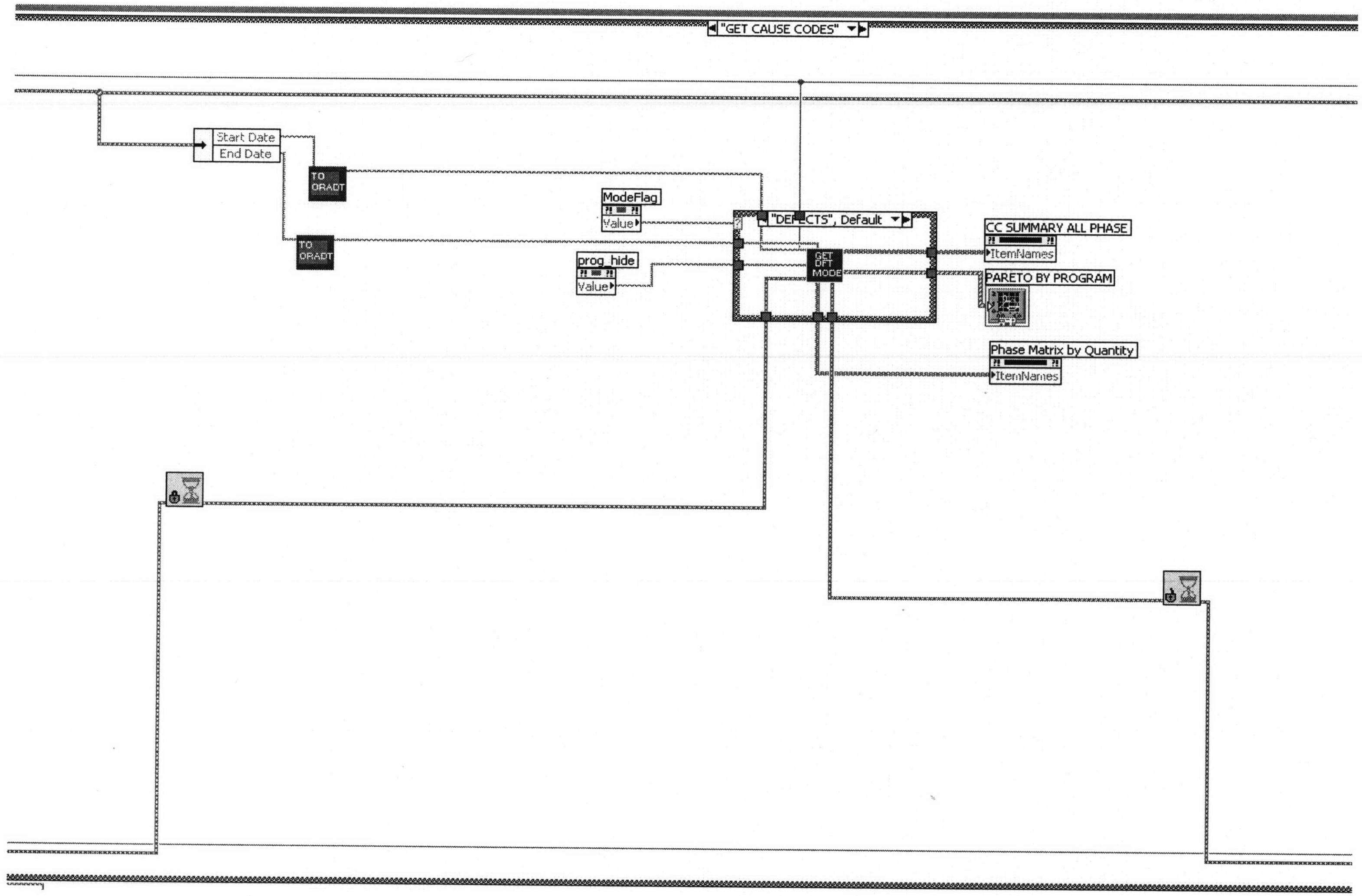

Figure 39. Sample VBS Dashboard LabView Development Code

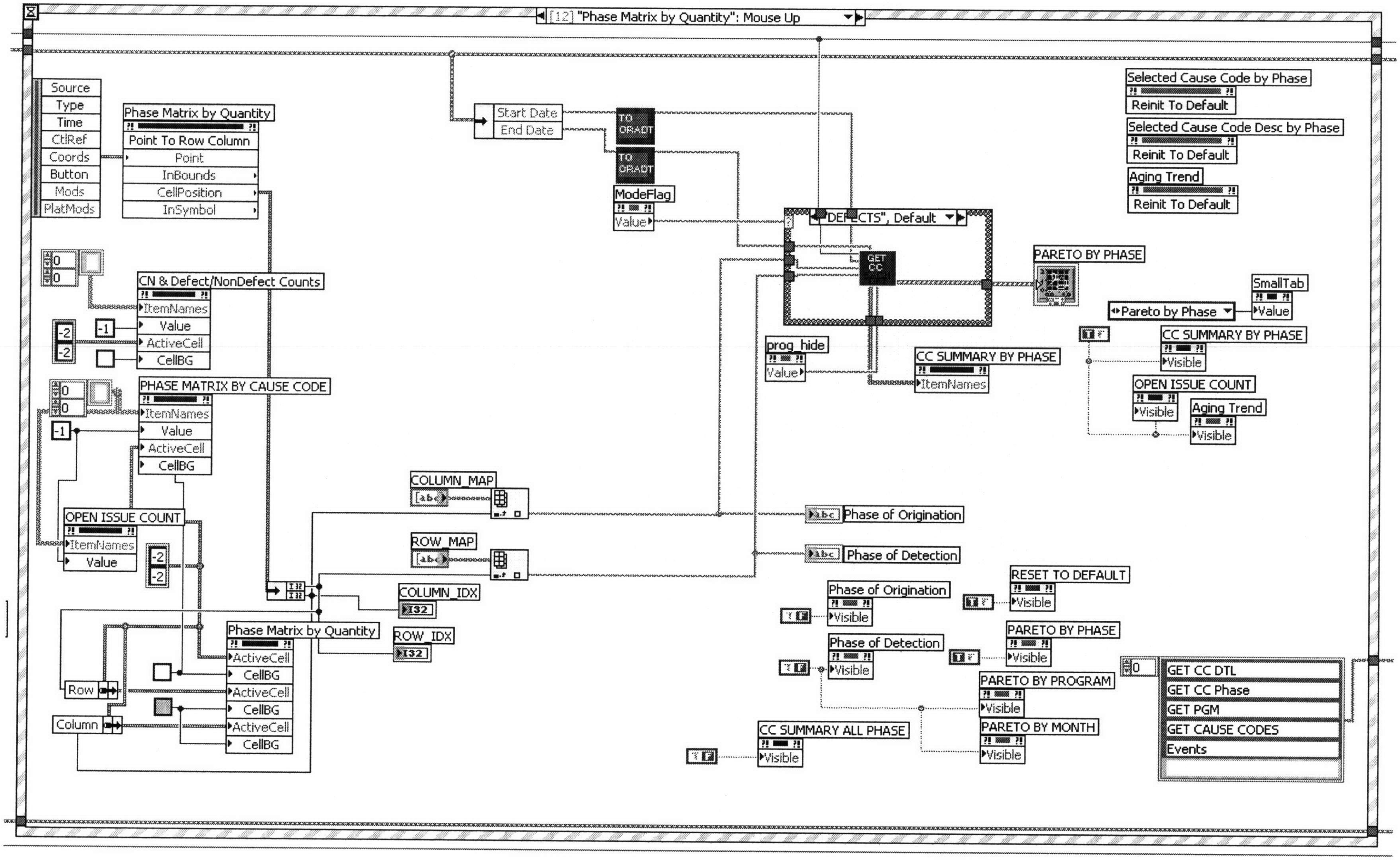

Figure 40. Sample VBS Dashboard LabView Development Code

VBS Copyright

The following copyright pertains to the screenshots and text contained in this thesis related to the Virtual Business Systems (VBS):