Using Visual Analytics to Drive Lean Behavior in Program Management Office

By

Charalambos J. Antoniou

M.S.E., Applied Mathematics & Statistics, Johns Hopkins University, 2004

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
Massachusetts Institute of Technology
June 2008

Signature of Author ____________________
MIT Sloan School of Management
Department of Engineering Systems Division
May 9, 2008

Certified by ____________________
Deborah J. Nightingale, Thesis Advisor
Professor of the Practice of Aeronautics and Astronautics and Engineering Systems
Co-Director, Lean Advancement Initiative

Certified by ____________________
Roy E. Welsch, Thesis Advisor
Professor of Statistics and Management Science and Engineering Systems

Accepted by ____________________
Richard Larson
Professor of Engineering Systems
Chair, ESD Education Committee

Accepted by ____________________
Debbie Berechman
Executive Director of the Masters Program, MIT Sloan School of Management

Using Visual Analytics to Drive Lean Behavior in Program Management Office

By

Charalambos J. Antoniou

Submitted to the MIT Sloan School of Management
and the Engineering Systems Division
on May 9, 2008
in partial fulfillment of the requirements for the degrees of

Master of Business Administration
And
Master of Science in Engineering Systems

Abstract

Raytheon recently won a large order for one of its programs (Program X) leading to a doubling of monthly production. With a relatively larger order, Raytheon reduced the acquisition unit price to the customer. Thus, there is a burning platform to evaluate the current program assessment tools and ensure that the future assessment tools are adequate for a smooth production schedule. In addition, there is a need to create a more robust and automated manner of identifying risks and opportunities in the production process.

The main approach is to use the Raytheon Six Sigma process (visualize, commit, prioritize, characterize, improve, and achieve) to solving major projects, which is similar to the original Six Sigma DMAIC process (define, measure, analyze, improve, control).

Using the aforementioned process, this thesis explores whether introducing visual analytics and controls to the Program Management Office (PMO) can improve the overall communication between the PMO and the manufacturing work centers, and ultimately eliminate the various wastes and improve Program X's production process. In addition, this thesis examines if driving Lean behavior to the PMO, can indirectly drive Lean behavior across the manufacturing value chain leading to cost savings and increased productivity.

Thesis Supervisor:	Deborah J. Nightingale, Thesis Advisor
Title:	Professor of the Practice of Aeronautics and Astronautics and Engineering Systems Co-Director, Lean Advancement Initiative

Thesis Supervisor:	Roy E. Welsch, Thesis Advisor
Title:	Professor of Statistics and Management Science and Engineering Systems

Acknowledgements

I would like to thank the Leaders for Manufacturing (LFM) Program and all its administrators for this great two-year journey in management and engineering. It has been an extraordinary experience. I will forever be grateful to LFM for providing me the opportunity to experience the greatness of studying at the eminent establishment of MIT.

I would like to thank Raytheon and its employees in the Integrated Air Defense Center located in Andover, MA. In particular, I would like to thank John Day for excellent mentorship throughout my stay at IADC. I also want to thank Roger Hinman for helping me identify several areas for my project and finally securing it. Without John and Roger's support this internship would not have been possible.

I would like to thank Manny Lopes, Mike Gosselin and Brian Martiniello for their outstanding support in driving Lean Behavior into the Program Management Office. In terms of access to the data and understanding the various data warehouses, I would like to thank Sean Kelly, Chris Darmetko and Mike Kaczmarski.

Thank you to my thesis advisors, Deborah Nightingale and Roy Welsch, for their guidance and support throughout the internship and during the preparation of this thesis.

Thank you to my fellow classmates in the LFM class of 2008. I will never forget the many great memories we shared over the two years at MIT.

Last, but most importantly, I would like to thank my family; my father and mother for always believing in me and pushing me to seize the opportunities across the world and my brothers Alex and Johnny for their love and support throughout the years.

Table of Contents

List of Tables

List of Figures

1 Introduction

This thesis explores the hypothesis that using visual analytics complemented with training in Lean principles can improve the communication and decision-making process of a program management office (PMO) and enhance a PMO's communication with the manufacturing centers. Consequently, the introduction of visual analytics and a mindset of Lean thinking should lead to better process controls and a mentality focused on process improvement for the entire program. The research for this thesis was performed at Raytheon's Integrated Air and Defense Center (IADC) in Andover, MA. For confidentiality reasons, the specific program will be referred to as Program X. This thesis covers the technical, cultural, and leadership aspects of attempting to drive change that were faced by an outsider (the author) working at IADC for a period of six months.

1.1 Burning Platform (Problem Statement)

Background: Raytheon recently obtained an order that doubled Program X's monthly production. Program X was supposed to be narrowing its production at IADC; however, demand started to pick up, particularly from foreign countries, which caused a surge in Program X's orders for the next 5 years.

Problem Statement: The lack of strong process controls for Program X and the increased production ramp-up caused management to reassess current process management tools. A team was assembled and co-lead by the author to 1) discover areas of waste, 2) prioritize these areas, 3) develop a plan to reduce the waste, and 4) ultimately implement a sustainable solution.

1.2 Thesis Organization

This thesis is organized into nine chapters as shown below.

- **Chapter 1 – Introduction:** Describes the problem statement and thesis organization
- **Chapter 2 – Company and Facility Overview:** Describes information regarding Raytheon and the details about the location of where the research was performed. In addition, it provides an overview of the stakeholders.
- **Chapter 3 – Raytheon Six Sigma (R6σ) Background:** Describes the process methodology used to tackle the leadership challenge at Raytheon's Andover facility. The process is called the Raytheon Six Sigma.
- **Chapter 4 – Literature Review:** Describes the external literature that was used as a basis to support the implementation of the research performed at Raytheon's Andover facility. It covers past LFM internships as well as several key research topics including Lean principles, data mining, and training techniques.
- **Chapter 5 – Case Study of Driving Lean Behavior using Visual Analytics:** Describes the bulk of the thesis. The layout of chapter 5 utilizes the Raytheon Six Sigma approach. The chapter is further divided into 6 major sections including Visualize, Commit, Prioritize, Characterize, Improve, and Achieve. The last three sections contain the majority of the process as they focus on 1) characterizing the problem including the leadership and technical challenges, 2) solving the problem using a technical and managerial approach and 3) finally presenting the results and developing a sustainability plan.

- **Chapter 6 – Recommendations:** Makes recommendations about Raytheon's Integrated Air & Defense Center (IADC) as well as the Virtual Business Systems (VBS) department.
- **Chapter 7 – Conclusion:** Provides a summary of the thesis and discusses potential next steps including follow-up internships to address the recommendations made in Chapter 0.
- **Chapter 8 – Bibliography:** Provides the list of references used in this thesis.
- **Chapter 9 – Appendix:** Shows the copyright disclaimer of VBS; a proprietary Raytheon software solution.

2 Company and Facility Overview

In this chapter, we introduce information about Raytheon and then drill down to focus on the particular scope of this project. We start out with the overall company, the business segment, the facility location, and the program area. The scope of the project resides in one of the components of the program area as shown below.

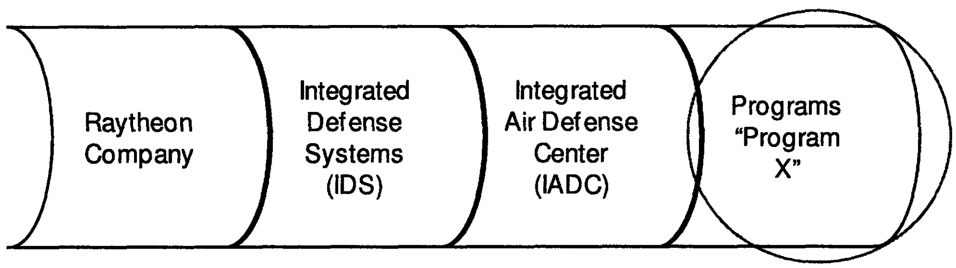

Figure 2-1: Project Scope Location Relative to Raytheon Company

2.1 Raytheon Company

Raytheon Company was founded in 1922 in Cambridge, MA as the American Appliance Company. In 1925, an Indiana company came forth and showed that it held claim to the American Appliance Company name, resulting in the new name of Raytheon which translates into "Beam of light from the Gods." "Ray" comes from French meaning "beam of light" and "Theon" comes from Greek meaning "from the Gods." (Raytheon Website)

According to Raytheon's 2006 Annual Report, Raytheon acts as a prime contractor or major subcontractor for several defense programs for the U.S. government, which accounted for 84% of 2006 Sales. It also provides solutions to customers in 80 nations worldwide. In 2006, Raytheon recorded net sales of $20.3 billion with approximately 80,000 employees of which 15% are unionized. (Raytheon, 2006)

Raytheon currently operates under six main business segments including: Integrated Defense Systems (IDS), Intelligence and Information Systems (IIS), Missile Systems (MS), Network Centric Systems (NCS), Space and Airborne Systems (SAS) and Technical Services (TS).

2.2 Integrated Defense Systems Division

The project was conducted within the IDS business segment, which is headquartered in Tewkesbury MA. IDS is a provider of integrated joint battlespace and homeland security solutions and its key customers include the U.S. Navy, Army, Air Force and Marine Corps, the U.S. Missile Defense Agency and Department of Homeland Security. In addition, IDS' key international customers include Japan, Saudi Arabia, Taiwan, Australia, Germany, Greece, and the United Kingdom. Overall, it provides solutions to 34 customers. According to Raytheon's 2006 Annual Report, IDS recorded net sales of $4.2 billion with approximately 13,500 employees (Raytheon, 2006).

IDS operates under six main business areas including: Future Naval Capability (FNC), Integrated Air Defense (IAD), Missile Defense (MD), International Operations Maritime Mission Systems (MMS), and Joint Battlespace Integration (JBI). The business areas are spread across 18 site locations, known as mission centers. This thesis is based on work performed in the Integrated Air Defense Center (IADC) located in Andover, MA.

2.3 Integrated Air Defense Center

As part of IDS, IADC is a 1.2 million square foot facility located in Andover, MA and primarily considered a manufacturing facility. It was built in the 1970s to act as the main manufacturing facility for the Patriot Air & Missile Defense System. However, it now includes several other programs including: Cobra Judy Replacement (CJR), AEGIS, and Ballistic Missile Defense Systems (BMDS). There are approximately 3500 employees of which 40% are unionized.

The organizational hierarchy of the facility is across two main dimensions: programs and value streams. Value streams at IADC are meant to represent work centers, mainly manufacturing centers. Work centers include Circuit Card Assembly (CCA), Surface Acoustic Wave (SAW), Metal Fabrication, Microwave, and Final Assembly.

In 2005, IADC focused more on its Lean transformation and brought in several Lean consultants to assess IADC's Lean maturity. The consultants conducted value stream maps, taught several Lean training classes, and helped coach IADC towards achieving operational excellence. Consequently, IADC was the 2008 Silver Medallion Recipient of the Shingo Prize for Operational Excellence.

2.4 Program X

This thesis observes the value chain of Program X. Program X can be described as a program that obtains old products from the field and upgrades them to the latest specifications. The value chain involves several manufacturing work centers and each work center performs several of the component upgrades. The manufacturing work centers are composed of Major Sections as well as Feeder Areas. The Major Sections deal with the top major components of Program X, whereas the Feeder Areas are the subassemblies of the major sections. A simplified process flow is shown below:

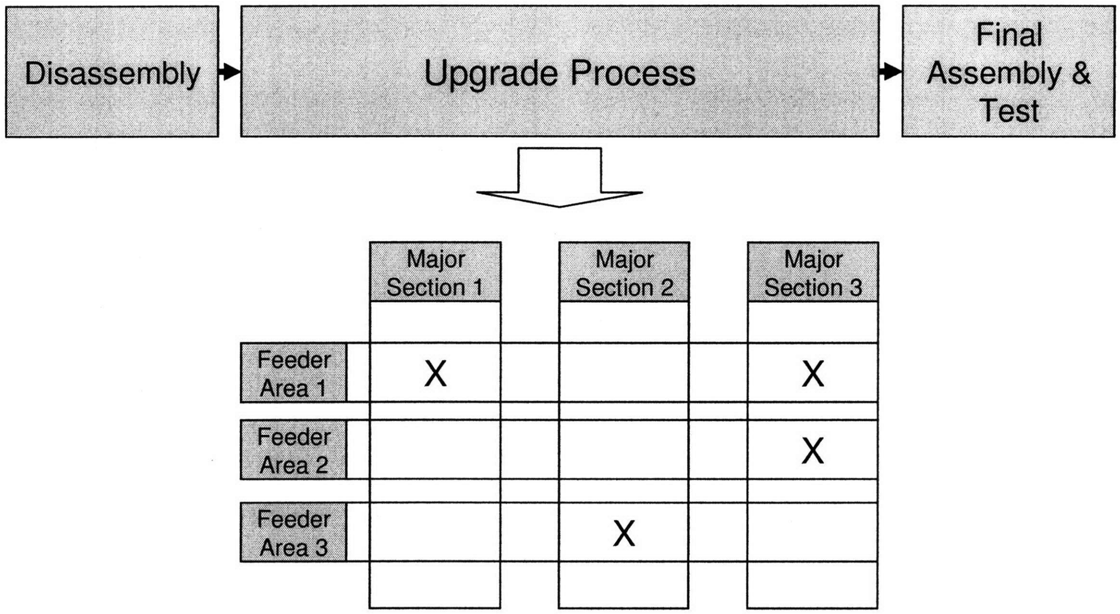

Figure 2-2: Simple Illustration of Program X's Production Process

Chapter 5 will cover in greater detail the communication flows among the various stakeholders shown in Figure 2-2, particularly, the wastes caused by the lack of standardized communication, information reporting and overall visibility into the process. The following chapter (Chapter 3) will provide the background necessary to understand the approach that was used by the author to solve Program X's poor performance assessment tools. The main approach used was the Raytheon Six Sigma process (visualize, commit, prioritize, characterize, improve, and achieve) to solving major projects.

3 Raytheon Six Sigma (R6σ) Background

Raytheon Six Sigma (R6σ) is an approach that utilizes a set of tools and principles geared towards helping change agents tackle on large scale projects. The tools and principles can be viewed as a combination of Six Sigma and Lean teachings as well as several other in-house best practices.

3.1 R6σ Overview at IADC

There are two designations awarded for completing the R6σ training modules: specialist and expert. The specialist title typically involves a project requiring around 90 days, whereas an expert project can last up to two years. Eventually, the experts become the coaches for the specialists. At IADC, it was very clear that the ideology behind R6σ is embedded in the DNA of the Raytheon employees. The majority of the employees were relatively familiar with the vocabulary associated with Lean and Six Sigma. Since the author was a change agent at IADC, it seemed appropriate to utilize R6σ as the approach to solving the problem statement (refer to section 1.1).

3.2 R6σ Process Overview

The framework for the case study in this Thesis is based on the R6σ model. Thus, this section will go over the basic mechanics of the R6σ framework. The process consists of six main steps: Visualize, Commit, Prioritize, Characterize, Achieve, and Improve. The bulk of the process lies in the last three steps, particularly the Characterize and Achieve steps. The six steps are typically depicted in the following circular diagram:

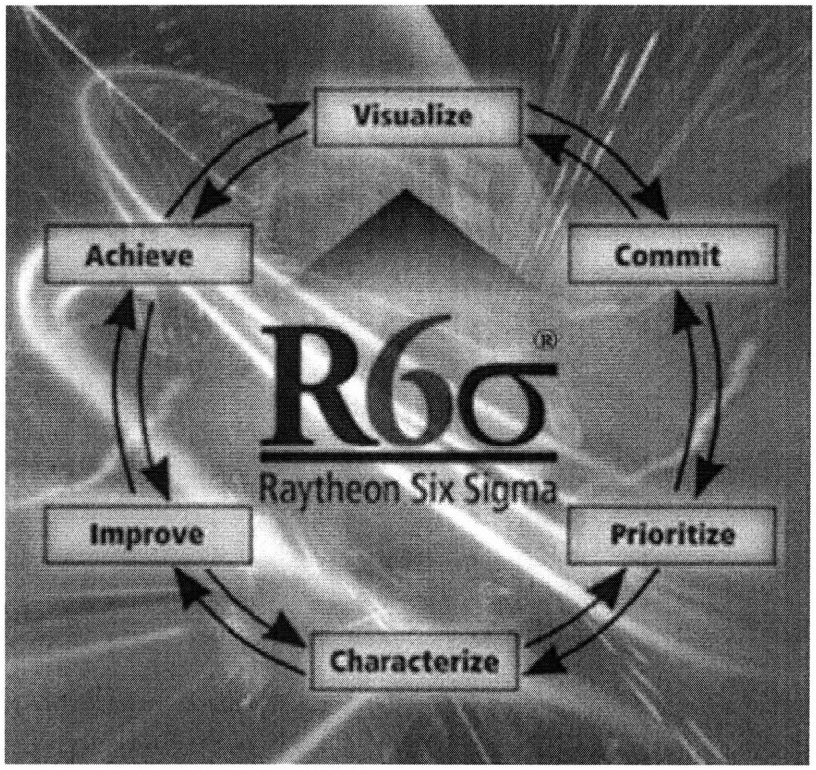

Figure 3-1: Raytheon Six Sigma Wheel (Raytheon Website)

The steps are defined as follows:

- **Visualize:** Define a vision statement and explain the burning platform (problem statement).
- **Commit:** Find a committed sponsor and develop a team that will be held accountable to deliver the vision.
- **Prioritize:** Define the objectives of the project with an emphasis on prioritizing the most important objectives relative to the various possible constraints, particularly time.
- **Characterize:** Document the current state performance in terms of metrics, process flow, and all other relevant factors.
- **Improve:** Design and implement the solution.

- **Achieve:** Capture the intended outcome and deliver results. Create a sustainable method for continuous improvement and knowledge transfer.

At the conclusion of a R6σ project, documentation is put together to capture all the research and solutions discovered. The aforementioned helps promote knowledge transfer across the facility.

4 Literature Review

The literature review chapter covers the research performed by the author that helped him to become effective during his internship at Raytheon. The topics of the literature review include:

- The past LFM internships at IADC that dealt with Lean principles and visual analytics.
- The set of Lean principles that were used as a guidance to help improve the dialogue between the author and the stakeholders of the project.
- The set of rules that guided the author to use IT as an enabler to Lean.
- The guiding principles of selecting the most appropriate metrics for assessing the health of Program X.
- The training methods that the author used to better communicate with the stakeholders of the project.

4.1 Past LFM Internships

Issac Newton once said "If I have seen further it is by standing upon the shoulders of giants (Bartleby.com)" when referring to his work and describing the work of other great physicists including Galileo and Kepler. Since 2000, Raytheon IADC has typically sponsored one to two LFM internships. In 2005, Neville McCaghren (LFM Class of 2005) utilized a performance metrics solution at IADC called "Visual Factory", later renamed to "Virtual Business System." The Virtual Business System (VBS) will be explained in further detail in section 5.5.2. McCaghren's work was focused on enabling process improvements using visual analytics in one of the manufacturing work centers;

the Microwave area. McCaghren's solution provided further evidence to the IADC employees that visual indicators can change behavior in a manufacturing setting[1].

In 2007, Dan Wolbert (LFM Class of 2007) took on applying the same hypothesis of using visual indicators to drive intended performance in the Material Inspection area of IADC[2]. Building upon the success of the previous internships, the idea of promoting greater visibility and access to real-time information leads to changing behavior became a potential solution to explore the issues raised by this thesis. This thesis is based on exploring the idea of driving Lean behavior in a Program Management Office (PMO) environment using visual analytics. Since it was already proven to work for the Microwave area and the Material Inspection area, there existed a pull from management to test the hypothesis that using visual analytics can drive Lean behavior in the PMO. A more detailed discussion about the motivation of the thesis will be presented in Chapter 5.

4.2 Lean Principles

A set of tools and techniques are limited if not combined with a set of principles that provide guidance and direction. The aforementioned was reiterated throughout the MIT LFM curriculum to the class of 2008 and heavily discussed in classes taught by Professor Steven Spear and Professor Deborah Nightingale. Most of the literature has praised the Toyota Production System, and all of them have documented the set of tools and techniques; however, not many companies have come close to reaching Toyota's level of quality and efficiency.

---

[1] Neville McCaghren was an LFM 2005 student and he was the first person to work with the VBS architecture from MIT.
[2] Daniel Wolbert was an LFM 2007 student and he was the second person to work with the VBS architecture from MIT

It has been argued by Spear and Bowen, that the missing ingredient to duplicating Toyota's success is the set of principles that guide Toyota's employees (Spear & Bowen, 1999). Consequently, the basis of this thesis is the implementation of visual analytics as a tool to drive the intended performance complemented with Lean principles as the guiding force to achieve that performance.

Most of IADC employees were already well versed in the set of tools and techniques preached by Lean and Six Sigma; however, there was no understanding of "why" a tool makes sense and "how" it is supposed to help. Furthermore, it seemed everyone was applying the various techniques simply because senior management mandates it.

The author attempted to bridge the gap between using visual analytics, and performance. Thus, there had to be a lot of training sessions and open communication that resulted in dialogues to better understand the "why" and "how" visual analytics can help the intended performance. In addition, during those sessions, the author attempted to help the stakeholders in understanding the larger theme of searching for new methods to process improvement (to be discussed in section 5.6.7).

The Lean principles that were used to help the stakeholders gain a better understanding of achieving the objectives are based on the rules that were set forth by Steven Spear and Kent Bowen. The rules include:

"The tacit knowledge that underlies the Toyota Production System can be captured in four basic rules. These rules guide the design, operation and improvement of every activity, connection, and pathway for every product and service. The rules are as follows:
Rule 1: All work shall be highly specified as to content, sequence, timing and outcome. **Rule 2:** Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.

Rule 3: The pathway for every product and service must be simple and direct. **Rule 4:** Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization
All the rules require that activities, connections, and flow paths have built-in tests to signal problems automatically. It is the continual response to problems that makes this seemingly rigid system so flexible and adaptable to changing circumstances."

Table 4-1: The Four Rules for Decoding the DNA of the Toyota Production System (Spear & Bowen, 1999, p. 98)

4.3 Information Technology as an Enabler to Lean

This thesis uses Information Technology (IT) to provide an environment for better decision making. The underlying use of IT is to promote Lean thinking and Lean Data. The assumption is that IT complemented with a mindset of Lean principles can help companies better compete in the marketplace.

Analytics are based on having an effective method for capturing data and converting it to information. Davenport and Harris (2007) provide a list of signposts of effective IT for analytical competition. The table below was the checklist used to ensure that the visual analytics solution developed at Raytheon's Program X was a model of excellence. All the listed bullets below with the exception of the last two bullets were implemented. Prior to the internship, none of the data management points shown below were implemented at Program X.

• Analysts have direct, nearly instantaneous access to data. • Information workers spend their time analyzing data and understanding its implications rather than collecting and formatting data. • Managers focus on improving processes and business performance, not culling data from laptops, reports, and transaction systems. • Managers never argue over whose numbers are accurate. • Data is managed from an enterprise-wide perspective throughout its lifecycle, from its initial creation to archiving or destruction. • A hypothesis can be quickly analyzed and tested without a lot of manual behind-the-scenes preparation beforehand. • Both the supply and demand sides of the business rely on forecasts that are aligned and have been developed using a consistent set of data. • Reports and analyses seamlessly integrate and synthesize information from many sources. • Rather than have data warehouse or business intelligence initiatives, companies manage data as a strategic corporate resource in all business initiatives. • High-volume, mission-critical decision making processes are highly automated and integrated. • Data is routinely and automatically shared between the company and its customers and suppliers

Table 4-2: Signposts of Effective IT for Analytical Competition (Davenport & Harris, 2007, p. 157)

4.4 Performance Metrics & Visual Analytics

According to Davenport and Harris (2007), companies are no longer simply collecting and storing data but are in fact using it as a competitive advantage (Davenport & Harris, 2007). They argue that most companies eventually tend to offer similar products and technologies, leading to business processes being the last method for differentiation among companies. Consequently, the basis for competition include "efficient and effective execution, smart decision making, and the ability to wring every last drop of the value from business processes – all of which can be gained through sophisticated use of analytics (Davenport & Harris, 2007)." This thesis builds upon the merits of using visual analytics and further explains it in chapter 5.

According to Politano (2003), the key to choosing performance metrics or key indicators is 1) it must be measured 2) it must matter 3) it must be manageable

(Politano, 2003). One cannot discuss metrics without addressing the difference between leading and lagging indicators. Investopedia.com describes leading indicators as indicators that signal future events, whereas lagging indicators are indicators that follow an event (Investopedia.com). This thesis attempts to use a combination of leading and lagging indicators. The leading indicators will be used as an attempt to capture risks in the production process before they escalate to major crises.

4.5 Effective Sustainability & Training Methods

The author strongly believes in continuous education as a method to train the stakeholders of Program X. Unfortunately, when it comes to technology training, it is seen by many as cumbersome and boring, resulting in the audience grasping very little of the information. According to Holmes (2007), "most software programs are used to about 10 percent of their potential (Holmes, 2007, p. 34)." Another aspect that is typically lost with training is that information is presented once. Based on the results found by Holmes (2007), repetition in training is essential to mastering a skill (Holmes, 2007, p. 28). The author opted to present information as a series of training workshops. The format of the training is another important aspect; while most of the group training sessions were demonstration based, the author also created several one-on-one training sessions to ensure that the stakeholders used the tools at more than 10% of their potential. The increased communication between the author and the stakeholders resulted in better capturing the needs of the stakeholders and ensuring that the visual analytics tool provided information that was valuable.

5 Case Study of Driving Lean Behavior using Visual Analytics

The layout of this chapter is based on the six steps of the Raytheon Six Sigma approach. The case study is based on the author's work during his internship at IADC with Program X. The following sections will demonstrate on a step by step basis the author's approach of driving Lean behavior to Program X by introducing a combination of visual analytics and Lean training to Program X's stakeholders.

5.1 Burning Platform (Problem Statement)

At Raytheon, the problem statement is typically referred to as the "Burning Platform." Consequently, this is typically the motivation behind using a R6σ process. The problem statement will be discussed in detail in section 5.1.1. Furthermore, a hypothesis will be generated in section 5.1.2 based on the details of the problem statement.

5.1.1 Overview

The need for change is based on more than one factor, because there are various stakeholders involved and all have slightly different objectives. Ultimately, the objective is to manage the ramp-up in production without doubling the number of resources.

Not only did demand double, but it also gave the customer more leverage in the bid negotiations. Thus, the customer mandated a lower unit acquisition price. Consequently, the PMO was tasked to reduce waste in Program X's production process. In other words, the PMO and the production staff from the manufacturing work centers had to work together to reduce waste and improve the efficiency in the current production process.

Although communication channels exist for both of the aforementioned entities to interact, they are still viewed as two different silos. The PMO did not have visibility into the manufacturing process because of two key issues:

- **Information Latency:** The PMO held meetings with the various manufacturing centers on a weekly basis. This included both the major sections as well as the feeder areas. The manufacturing work centers would report the issues to the PMO as well as open the discussion with the other work centers regarding potential upcoming risks in the production line. Typically, each work center did not have visibility into the process of other work centers. Thus, each work center could not gauge the potential risks and opportunities stemming from a lower assembly. The process of data gathering can be at best described as a manually intensive process that required each work center to dedicate approximately 10% of their time towards the data gathering function. The majority of the meetings were on presenting facts and very little time was spent on identifying risks and opportunities.
- **Data Integrity:** There was no consistent source used for report generation, and many times during the meetings, the time was spent reconciling numbers. For example, a major section would say that they received 15 completed units from a feeder area; however, the feeder area would say it completed 20 units. It turns out they were both right, but differed because of when they saw the data, or which system they used to find the data. Some systems are updated daily whereas other systems are updated weekly. A more detailed explanation will follow in section 5.5.1.

It seemed that several undesirable effects were happening because of the lack of visibility into the details. Those effects can be summarized as:

- **Increased costs due to data gathering and reporting:** Additional resources were required for data gathering and reporting. Some manufacturing centers dedicated a full-time resource for report generation while other centers made the report generation part of the many functions of the centers' leaders.
- **Issues are discovered later in the process:** With the latency in information reporting, the damage has already taken place. Thus, all the performance metrics reported aren't being utilized properly or for the intended purposes of measuring the health of the PSML program.
- **Increased tension among stakeholders:** Given the variability in the process, the higher assemblies (major sections) were requiring their feeder areas to overproduce. Consequently, the feeder areas would typically have a higher buffer stock than needed. The feeder areas support several programs, not only Program X. The aforementioned situation causes an unnecessary constraint on the resources and creates inaccurate capacity planning projections.
- **Lack of projects geared towards process variability reduction:** Given that there were issues due to data integrity, there was always a pushback regarding projects focused on analyzing the data with respect to finding the variability of the various processes. Thus, the majority of the projects used experience and not actual data to solving issues. Although experience has its merits, given the fact that the capacity utilization of Program X on the feeder areas changes depending on the demand of other programs at IADC, there should be a method that would

be able to at least validate the past historical production (stemmed from experience on the process) to the actual production. There exists a reference of the manufacturing time for each operation of a part number. The author cross-referenced several of those operation times to the actual times of one part number over a period of 6 months, and found that about 30% were significantly inaccurate.

- **Delaying critical decisions due to inconsistency in reporting:** Since the facts were not consistent from one group to another, it resulted in making critical decisions later in the process. In addition, it resulted in not having much honesty in the discussions. Consequently, the stakeholders felt that some groups were not disclosing all the facts.

5.1.2 Hypothesis

From section 5.1.1, it started to become apparent that one of the major areas for the enterprise to reduce waste is to improve the communication link between the PMO and the manufacturing work centers.

Thus, the hypothesis is: "can introducing visual analytics and controls to the PMO help the overall communication between the PMO and the manufacturing work centers, and ultimately eliminate the various wastes and improve Program X's production process?" In addition, the hypothesis will try to explore if driving Lean behavior to the PMO, can indirectly drive Lean behavior across the manufacturing value chain.

5.1.3 Internship Deliverables and Pull from Different Stakeholders

There are several stakeholders who stand to benefit from the results of the internship including the PMO, manufacturing work centers, engineering, IADC's office of continuous improvement, VBS developers, and ultimately the end customer. The table below shows the motivation behind the internship and lists the deliverables requested by the various stakeholders.

Pull From PMO "Key Deliverable"	• Better assess Program X's Health ➢ Enhance review meetings ➢ Eliminate manual process of data gathering ➢ Provide more time for stakeholders to focus on reducing cost, improving the process and eliminating waste
Pull From Raytheon IADC "Secondary Deliverable"	• Continue Lean Journey ➢ Implement Lean into other areas not just manufacturing including Program Management Office ➢ Be ready for Shingo Review ➢ Improve communication between stakeholders
Pull From Customer "Future Vision Deliverable"	• Lower unit acquisition cost (Eliminate waste!) ➢ Program X recently won a large contract causing monthly production to double for the next year. ➢ Program X is projected to experience even higher growth over the next 5 years due to increased international orders.

Table 5-1: Internship Motivation (Pull from Three Different Stakeholders)

5.2 Step 1: Visualize

Given all the undesirable effects caused by information latency, data integrity and miscommunication among the stakeholders, there was no method to obtain an accurate representation of Program X's health. Thus, it seemed that the use of visual analytics might be a solution that would have multiple benefits. It would also be able to drive Lean behavior to the PMO, particularly the PMO's interaction with the manufacturing work centers. In addition, it would show the manufacturing work centers several performance metrics that would help the entire program identify risks and opportunities.

Thus the vision statement is "To create an automated, fully integrated, real-time visual analytics and controls system to get an accurate representation of the program's health and drive lean behavior into Program X's meetings." To restate the importance of the vision statement in the words of one of the most acknowledged gurus of quality; Deming (2000) said "Break down barriers between departments (Deming, 2000)." In other words, this report will attempt to break down the barriers between the PMO and the manufacturing work centers.

5.3 Step 2: Commit

In order to drive a major change, there was a need to ensure a team was assembled and committed to the project. Prior to the work performed in this thesis, the Program X's PMO had declared that it needs to create a more robust method for assessing the health of the program. However, at the time, it was unclear to the PMO how to go about achieving their objective. After discussing several options, the idea of using a visual system to capture several important performance metrics seemed like a step in the right direction.

The timing of the PMO's initiative coincided with the start of the author's internship. The author, with the help of a R6σ expert, led the initiative. The PMO as well as senior management at IADC declared their support for the project. Although, there was buy-in from the "top", there was a lot of resistance from the manufacturing work centers, particularly the cell leads of the feeder areas.

The feeder areas manage multiple programs and their concern was they have no time to learn or use the system. The major sections of Program X were more acceptable to new changes as they only focused on Program X. All the cell leads were already trained in Lean principles and most of them were R6σ specialists. Thus, they were always in the spirit of continuous improvement.

There was strong support from senior management, the cell leads of the major sections, and some of the cell leads of the feeder areas. Powered with the aforementioned support, the project started on a positive track.

5.4 Step 3: Prioritize

This step focuses on prioritizing the list of objectives to ensure that the project yields results sooner than later. By communicating the list of immediate objectives to the various stakeholders, it became relatively easier to focus on the deliverables. The main goals of creating a visual analytics system were to help both the PMO and the manufacturing work centers in their daily activities. In other words the system was designed to:

- Drive Lean behavior to the Program X's PMO and build awareness of Lean principles
- Identify bottlenecks in the manufacturing value chain.
- Identify risks in the process before they become major crises.
- Identify long-term opportunities focused on reducing the variability across Program X's major sections as well as the feeder areas.
- Nourish an engaging environment for employees, particularly the interaction between the PMO and the manufacturing work centers.

5.5 Step 4: Characterize

5.5.1 Data Sources

IADC's IT infrastructure can be described as a mix of enterprise-wide applications as well as stand-alone applications developed for a particular business unit. At IADC, there is a centralized manufacturing application called "Shop Floor Data Manager (SFDM)", which was developed by Industrial Computer Corporation in the early 1980s. Over the years, there have been several enhancements to SFDM. There exist multiple MRP systems across Raytheon and the one used at IADC is referred to as AIMS (Armitage Industrial Management System), which was developed by Armitage Technologies Limited. The budget (financial) data exists across multiple systems. Solutions developed by SAP are the predominant software used for reporting and collecting financial data.

SFDM is used primarily for collecting data and is available instantaneously. AIMS is used for both collecting and reporting of data. However, the reporting functionality is relatively limited and is at best described as reporting data of one metric for a single item per screen. SFDM and AIMS are legacy systems and considered by many employees throughout the facility to be "archaic." A few years ago, there was a business plan to upgrade all the manufacturing and MRP systems at Raytheon to use enterprise-wide applications; however, the upgrade has yet to occur and is seen as not likely to take place anytime soon at the IADC facility. However, most Raytheon's facilities in the west coast have already implemented the upgraded MRP and manufacturing systems.

IADC management is accustomed to obtaining reports in some type of Microsoft Office format including excel reports, access reports or powerpoint reports. There are also several other applications including products by Cognos Business Intelligence. Other users also use some reports generated by an in-house reporting tool called Virtual Business System (VBS), which will be discussed in greater detail in section 5.5.2.

Program X's PMO was accustomed to a plethora of Microsoft excel reports. Each manufacturing work center would compile its own report. There was no consistent method for reporting the data or using a consistent data source. This resulted in many scenarios where the PMO would struggle with the manufacturing work centers trying to reconcile the data. In addition, since data existed across multiple systems, it was a manually intensive process that would attempt to compile an aggregated view. Ultimately, the PMO could not use a data-driven approach to decision making and had to rely on anecdotal data, which has the potential to lead to several undesirable effects.

5.5.2 Virtual Business System (VBS) Culture & Community

Virtual Business System (VBS) is an IT enabler for Lean principles. The solution attempts to tap into the many legacy systems available at IADC and collect one aggregate view. Furthermore, VBS provides a customized reporting methodology by leveraging the concept of visual dashboards to convert data into critical information used for real-time decision making.

The VBS solution was called "Visual Factory" and was founded in 2004. VBS was initially developed in the Microwave area of IADC to help provide real-time performance metrics in order to identify risks before they become crises, leading to a significant reduction of the unit cost of a Transmit/Receive Integrated Microwave

Module (TRIMM). In 2005, when IADC started its Lean journey, senior management chose VBS as the solution to monitor Lean behavior. With the help of the Lean office (now called office of continuous improvement), VBS created a maturity model for assessing Lean behavior in a real-time manner. This Lean assessment tool by VBS can be compared to MIT's Lean Advancement Initiative (LAI) Lean Enterprise Self Assessment Tool (LESAT)[3]. The VBS Lean assessment tool captures relatively less data, but in a real-time manner.

VBS was a very familiar tool for the majority of the operators on the floor; however, it had yet to become a common application in an office environment, particularly, the program management office.

5.5.3 VBS Development Environment

VBS chose LabVIEW, a product by National Instruments, as the development environment to create the visual analytics and controls. The initial reasons behind using LabVIEW were because of its scalability, affordability and familiarity amongst Raytheon engineers.

According to the National Instruments Website, "For more than 20 years, NI LabVIEW graphical development has revolutionized the development of scalable test, measurement, and control applications (National Instruments Website)." The graphical programming method allows for an easier introduction to programming. Unlike most programming languages, with LabVIEW, the user interface is developed prior to the coding, whereas, in most other programming languages, the user interface is the last part of the coding.

---

[3] There are several good references on LESAT available at:
http://lean.mit.edu/index.php?option=com_content&task=view&id=351&Itemid=310

Virtual Instruments (VIs) are the main file format produced by LabVIEW. VIs contain both the controls (buttons, knobs, etc.) and the indicators (graphs, tables, etc). VIs can be converted into executables that run on any PC. The PCs require the LabVIEW runtime engine, which is a free application. In other words, users of VBS simply require one simple download which includes the LabVIEW runtime engine as well as other Raytheon specific security files in order to start using the dashboards created by the VBS community.

With any development environment there are always advantages and disadvantages. However, the analysis was made and it showed that the advantages of using VBS far outweigh the disadvantages. In terms of advantages:

- **Familiarity amongst employees:** According to McCaghren (2005), Raytheon has used LabVIEW for control test equipment and has well over 1000 trained users (McCaghren, 2005)
- **Ease of programming:** The graphical programming approach makes it a lot easier for non-programmers to understand the code. Consequently, the new programmers can make immediate changes in a very short period of time. In addition, since the programming structure is relatively modular, there is a lot of code that can be easily reused. Thus, a lot of the complex coding structures have already been identified and are now easily reusable by novice LabVIEW developers.
- **Speed of Deployment:** Applications can be developed relatively quickly due to the easiness of programming as mentioned above. Thus, solutions are deployed faster than other applications which require a relatively more rigorous approach.

In terms of the disadvantages, the main disadvantage is that LabVIEW was not intended as a business intelligence tool. Thus, a lot of the functionality that might seem as commonplace with typical business intelligence tools is missing from the LabVIEW development environment. However, the VBS team has throughout the past years managed to create a repository of code that mimics a lot of the functionality found in the typical business intelligence software.

5.5.4 VBS' Role in Aggregating Data

In trying to centralize the many sources of data, it was found that VBS had developed a relatively interesting approach to extracting data from the various legacy systems. VBS uses relational databases to communicate with the data. Initially the data is collected in legacy systems which produce output files that are cumbersome to navigate. Consequently, the IT department wrote a plethora of queries to extract the data from the legacy systems and present them in relational databases. The database is based on an Oracle Database[4].

There is a lot of data that is captured by the legacy systems, but not all of it can be synthesized to relevant performance metrics. Thus, VBS decided to only extract key data from the Oracle servers to a local server. The local server, VBS Server, is based on Microsoft SQL Server. The reasoning behind extracting the information locally is to ensure that the access to the data from the dashboards is relatively fast. The alternative would be to directly access the data from the Oracle servers; however, it was found that access to the Oracle servers takes a relatively longer period of time compared to having

[4] Check http://www.oracle.com/technology/obe/11gr1_db/index.htm for more information regarding Oracle Database application.

the data stored locally on the VBS server. The figure below provides an illustration of VBS' data architecture.

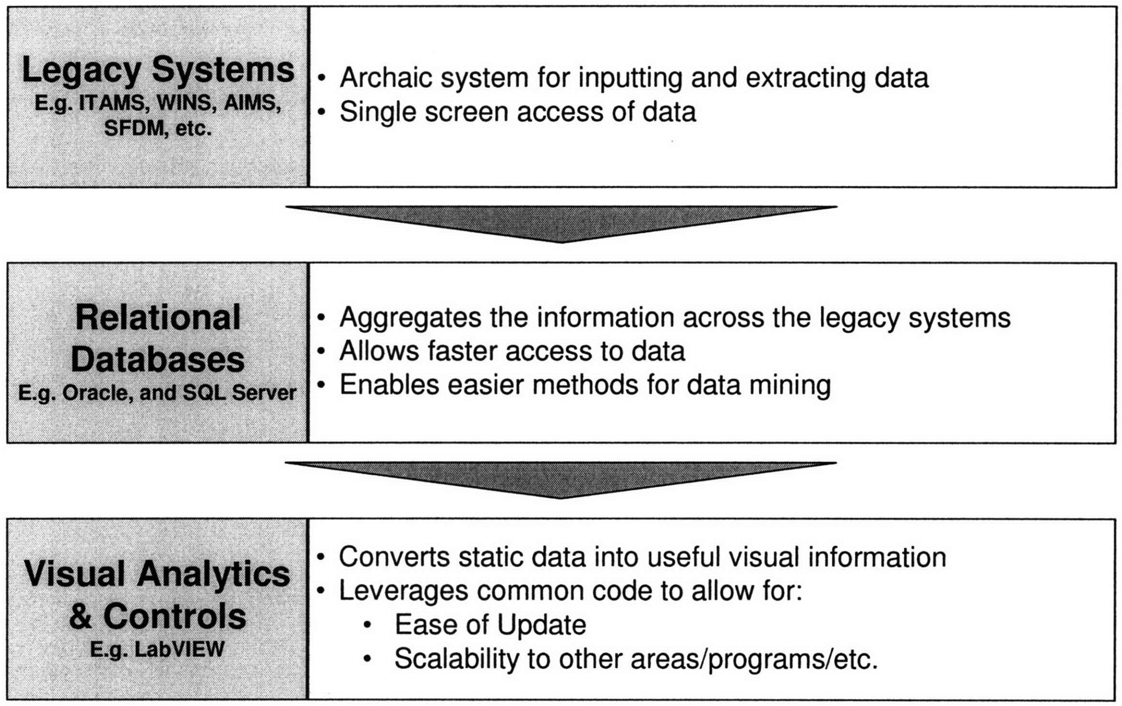

Figure 5-1: Illustration of VBS' Data Architecture

5.5.5 VBS' Role in Promoting Lean

As mentioned earlier, VBS has developed a real-time Lean assessment dashboard that records and tracks the maturity of a cell throughout its Lean journey. VBS created a common ground to compare all cells in a manufacturing environment. Furthermore, VBS is an integral part of IADC's Lean journey. In 2005, VBS was highlighted by The Office of Naval Research's Best Manufacturing Practices (BMP) Program as a Best Practice (The Office of Naval Research's Best Manufacturing Practices (BMP) Program).VBS continues to reach out to the various areas of IADC to help the areas gain a better understanding of using processes and problem-solving methodologies to identify risks and opportunities before they turn in to major issues and concerns.

As VBS has matured into one of the best methods of enabling Lean at IADC, it developed a series of principles listed below (Day, 2007).

- Performance data is used to identify and solve problems as they occur – not after the damage is done
- No non-value added work is required to view critical data – just like the lights, the necessary data is there
- Data is active – not to be viewed at your leisure : it comes after you
- Actionable data is continuously delivered to people who can improve performance
- Critical data is being used to make decisions and influence behavior – and you know it

The aforementioned principles embody the core culture and vision of VBS. The above principles were always used to demonstrate to the various Program X stakeholders that VBS can in fact help improve their efficiency at work and ultimately reduce the costs of Program X.

5.5.6 Communication Overview between Program Management Office with Manufacturing Work Centers

Program X's PMO works with both the customer and the manufacturing work centers. However, most of the effort of the PMO is focused on the customer. As noted in section 2.4, the manufacturing work centers are split into two different areas: Feeder Areas and Major Section Areas. The Feeder Areas have multiple programs other than Program X that they cater to. whereas the Major Section areas cater only to Program X. Currently, there are no communication channels available for conflict-resolution or crisis situations. In other words, the PMO is not in a position to easily identify risks and opportunities to help the manufacturing work centers meet the customer demands. There appears to be a sense of concern between the feeder areas, the major section areas, and the PMO. Given the lack of visibility into the process, all of the aforementioned stakeholders tend to always be skeptical about each other's actual performance. During meetings, the PMO would blame the major sections for delays, and in the same manner, the major sections would blame the feeder sections for delays. The feeder sections would then start blaming another silo group (suppliers, engineering, supply chain, etc.). Again, given the lack of visibility into the process, it was always a case of never finding a person or group accountable early on in the discussions.

5.5.7 Leadership Challenges

After assessing the problem, it was clear that the biggest waste in Program X's world was the communication link between the PMO and the manufacturing work centers. Thus the majority of the effort was on trying to establish better communication among the stakeholders. The PMO wanted to improve its relationship with the manufacturing centers as well as gain visibility into the production process. However, the manufacturing centers did not want to provide the support needed as they preferred to keep the PMO on a "need to know" basis. The first challenge was to convince the manufacturing work centers that sharing information and increasing visibility into the process can actually lead to superior results. In order to obtain initial buy-in from the manufacturing work centers, the author had to establish a basis for credibility using a series of quick wins that proved useful to the work centers. The wins included automating several of the manual data gathering reports. The manufacturing work centers had initially dismissed the notion of automation of data gathering citing that data is across many legacy systems and there is no accurate method of aggregating it. However, after numerous trials, the author and his team were successful in automating several reports. This lifted the morale of the manufacturing work centers because they all used to complain about the time it takes to gather and generate reports.

After a basis for credibility was established by the author, he had greater leverage to work with the stakeholders and understand the underlying concerns about managing Program X. The team shared ideas about better managing the process (later discussed in section 5.6). The atmosphere changed drastically from a hostile environment to an extremely friendly environment where open communication was encouraged. The importance of the aforementioned is that when attempting to introduce a change several questions need to be addressed. According to the theory of constraints (TOC) of AGI-Goldratt Institute, the questions that need to be answered include:

• Is the right problem being addressed - mine? • Is the general direction that the solution is heading a good one? • Will the solution really work to solve the problems and what's in it for me? • What could go wrong? Who might get hurt? • How the heck are we going to implement this thing? • Are we really up to this? Do we have the leadership and the commitment to pull this change off successfully?

Table 5-2: Theory of Constraints: Overcoming Resistance to Change (AGI-Goldratt Institute)

All the questions were discussed among the stakeholders, but it did not happen at the initial meetings. On the contrary, the discussions happened after the manufacturing centers eased up to the idea of change. They eased up to the idea after they noticed there is some tangible gain for them.

5.5.8 Technical Challenges

Although the PMO did not specifically seek out a technical solution, they realized that in order to achieve the objectives of process improvement and gain visibility into production, the most obvious solution would be to automate all the manual data generation and data reporting procedures to alleviate the pain that the manufacturing work centers had to endure to gather and generate the reports for the PMO. Given the short period of time of the internship, it was critical to develop, design, test, and implement a solution relatively fast. Although the author had no prior experience in developing code using LabVIEW or an understanding of databases, there was enough support from the VBS team to help the author get started. The author also had several issues with data access and data geography. In other words, given a lack of documentation on the data across the legacy systems, it was neither clear where the data existed at IADC nor a clear method to extract it. In addition, there were no experts on the data because employees moved around constantly.

5.6 Step 5: Improve

This section will discuss the improvements made to address the burning platform as outlined in section 5.1.1. The main solution was designing, developing, implementing and testing a visual analytics dashboard. The author was the lead developer of the visual analytics dashboards. There were two dashboards developed; a main dashboard to provide the analytics and a sustainability dashboard that was used to customize the main dashboard. The author co-developed the main dashboard whereas he was the only developer on the sustainability dashboard.

The author also conducted several training sessions that involved explaining the tools as well as explaining Lean principles, which helped the author with spreading the visual analytics tool across the stakeholders as well as obtaining buy-in from other programs. For confidentiality purposes, many of the figures and tables in section 5.6 will be disguised with fictional data or blank data. However, the figures and tables will prove useful to illustrate the capabilities of the system developed.

5.6.1 Overview VBS Dashboard Solution (Main Tool)

The VBS Dashboard solution created to address the problems facing Program X's PMO was called "PGM_REVIEW." The reason for not having the title of the dashboard associated with Program X is because there was a realization that the problems facing Program X might not be limited only to Program X but could also exist for other programs. Thus, the VBS Dashboard was a short-hand format of "Program Review." This allowed for easier marketing of the dashboard to other programs. The dashboard focused on addressing three key areas of interest for the stakeholders; Information Reporting, Risk Assessment and Employee Engagement. Broadly speaking, the interest areas include the following information.

- **Information Reporting:** The stakeholders wanted to automate all the reports and metrics generated by the manufacturing centers to serve Program X's PMO. In addition, they wanted to assess if the current metrics were appropriate given the scalability of the program in 2008 and 2009.
- **Risk Assessment:** Information reporting can only go so far, but most importantly, the PMO realized that it is far better to find issues early on before they become

major risks affecting Program X. Thus, the solution also needed to easily identify risks and opportunities for the user.

- **Total Employee Engagement:** In order to foster better communication among the stakeholders, the solution should be able to pool all the stakeholders together and enhance the communication among them. A key idea was the ability to easily create teams to solve the risks identified from the Risk Assessment section.

The stakeholders also felt that the task list above should be able to address the following four questions:

- **Identifying Bottlenecks:** Who is Herby (Goldratt, 2004)[5]? Where are the constraints?
- **Identifying Risks:** Which are the Dog items with the greatest risk?[6]
- **Identifying Opportunities:** Where are the largest variability areas?
- **Improving Total Employee Engagement (TEE):** How can I nourish an engaging environment for my team?

5.6.2 Identifying Bottlenecks

Given the nature of Program X, demand is typically fixed for approximately 6 months. Any additional demand incurred would not actually be scheduled for production or delivery until after a few months. In addition, to upgrade one product of Program X, it requires exactly one assembled part from each of the major sections of the manufacturing work centers. Given the aforementioned scenario, a unique opportunity exists to discover

[5] Herby is portrayed in the novel as the slowest person holding up a line in a process, also known as the bottleneck.

[6] A "Dog" item is referred to an item in production that is simply not worth pursuing and is a target for a similar action like divestiture. The analogy is loosely based on the BCG Growth-Share Matrix (ICMBA)

the bottleneck in Program X's production process. Coupled with the fact that demand is known, we can calculate the metric of "Past Due" relative to demand.

The PMO only cared at a high level which of the major sections was holding up the process, whereas the major sections were concerned by which feeder section was holding up the process. Thus, in order to satisfy both requirements the concept of generating a dashboard that would easily switch from the PMO view to a major section view was critical.

In order to satisfy the concerns of the stakeholders, this idea of creating "reports" was introduced. The reports concept can be analogous to viewing the bill of materials of a certain product one level at a time. Thus, the PMO would view the top level. On the other hand, the major sections of the manufacturing work centers would view the second level and so on. In addition, each report will consist of columns with the headings of the various part numbers. The leftmost column will be the next higher assembly for the combination of all the other columns. For example, if we wanted to observe the report of a Major Section (MS1) then the leftmost column would be the MS1 and all the columns next to it would be the various subassemblies. From Figure 5-2, we can compare the past due (PD) metric across columns and quickly identify the constraints in the process.

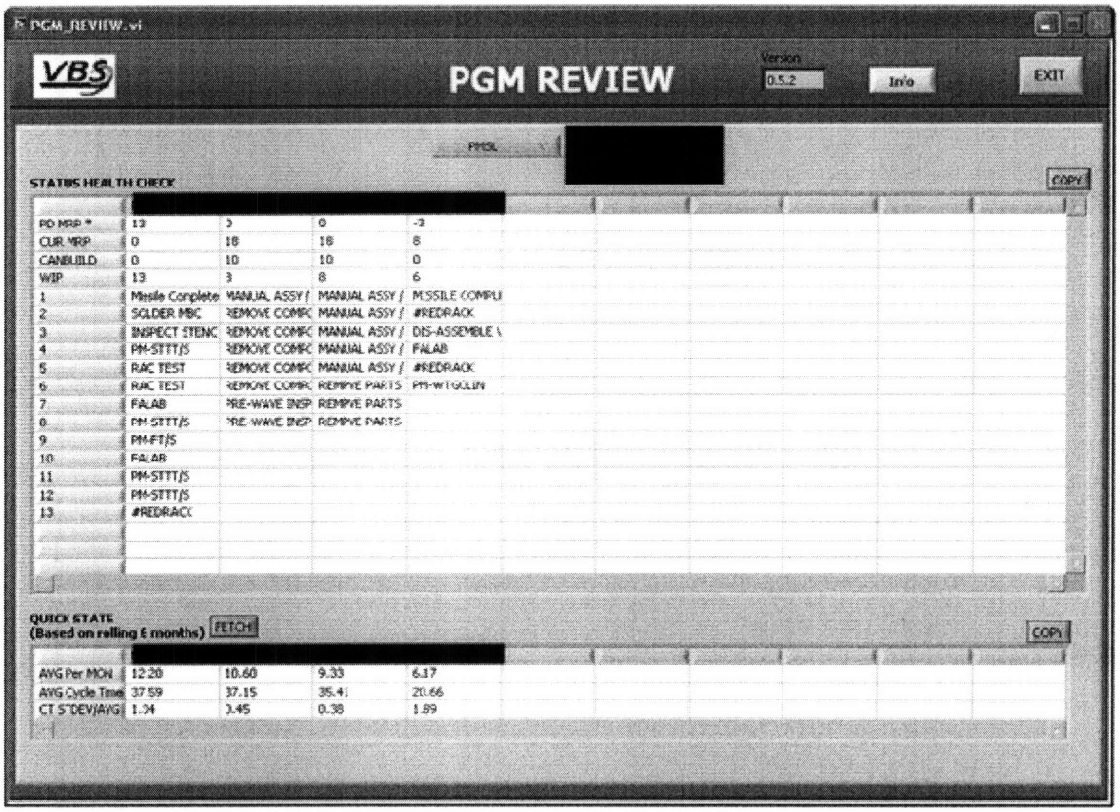

Figure 5-2: Main screen of PGM_REVIEW for a random major section

We notice that the leftmost column shows a PD of thirteen whereas the lower subassemblies show zero or a negative number! That would translate that there should be no PD for the leftmost column. However, this particular example was highlighted to show the various issues that would have risen in the past in a PMO review meeting and given the lack of visibility in the details ended up causing tensions among the stakeholders. Some areas would hide the past due issues and push them to the current month demand.

At a closer look into the details we notice that although past due demand seems to be satisfied for the lower subassemblies, their CUR MRP (current month demand) is high. A more appropriate perspective (that was never actually stressed enough in the stakeholder meetings) was to look at both metrics combined in order to avoid any type of misunderstanding. Furthermore, we notice that the second and third column have similar figures and it is not clear which is holding up the process. They show that both need 18 parts to meet past due demand and this month's demand. Assuming that both part numbers started at the same time and there were already enough items in WIP, then the veteran manager would be able to predict which part number was in fact holding up the process (given that he/she has an understanding of the cycle times). Another note is that demand of the subassemblies does not need to be exactly the same demand of the higher assembly for the month because of the different cycle times.

We notice that in order to get a full picture, there is a need for more relevant information such as the descriptive statistics of the time it takes to complete each part number as well as information regarding the WIP of a part number. From Figure 5-2, we notice that it shows all those key metrics to help with answering the question of identifying the bottleneck. A summary of the metrics shown in the figure include:

- **PD MRP:** Calculates part numbers that were considered "Past Due" relative to demand.
- **CUR MRP**: Shows the "Current Demand" of the month for the part numbers
- **Canbuild:** Shows the "Canbuild" status. "Canbuild" is defined as a part number that is kitted and is waiting to go on the floor. In other words, when a part number is kitted, it means it has all the necessary items from the feeder area and is ready to move to the next major section area. If there wasn't enough WIP to satisfy the demand, then the canbuild metric would be used to hold accountable the specific group for not releasing the appropriate amount into WIP in order to meet demand.

- **WIP:** Shows the total number of parts currently in WIP. This metric is used to understand if there is enough WIP to meet demand. However, the metric alone is not sufficient unless we take into consideration the current time of the month and the cycle time of the part number
- **Text below WIP:** Each part number has a fixed number of standardized steps (or operations) that it needs to complete. Those are referred to as "on router." If an issue arises, a part might need to be removed and go into rework, called "off-router." The text refers to the operation description.
- **AVG Per Mon:** Shows the average monthly production over a 6-month period
- **AVG Cycle Time:** Shows the average cycle time for a part number over a 6 month period.
- **CT STDEV/AVG:** Calculates the coefficient of variation of cycle time. This metric is used to check the variability in the process of a particular item and gives a good comparative across the key items of an assembly (discussed in more detail later).

One of the strengths of using the VBS architecture is that VBS has figured out a way to tap into all the legacy systems across IADC, thus making it possible for easily creating more drill down options. From Figure 5-2, each of the cells within the four top rows leads to another screen with drill down capability.

For example, the canbuild row for the third column shows a number of ten, which indicates that there are ten items ready to be kitted. By clicking on the cell it navigates to another window that shows the details as well as any other items that are missing components in order to be kitted. That drill down detail was never regularly pulled by the stakeholders because it was an extremely manual intensive process. It would take days to accurately fetch that information for one specific part number. However, with the help of VBS, the aforementioned drill-down capability is now available instantaneously for any part number.

Many of the members from the manufacturing work centers were extremely delighted with having the ability to find the canbuild information. It was one of the key turning points for many users. Some users at first were reluctant to use the dashboard, but as they discovered that it had information they actually needed, and made their life easier in terms of gathering other data, there was a jump in the usage. A sample screen shot is shown below.

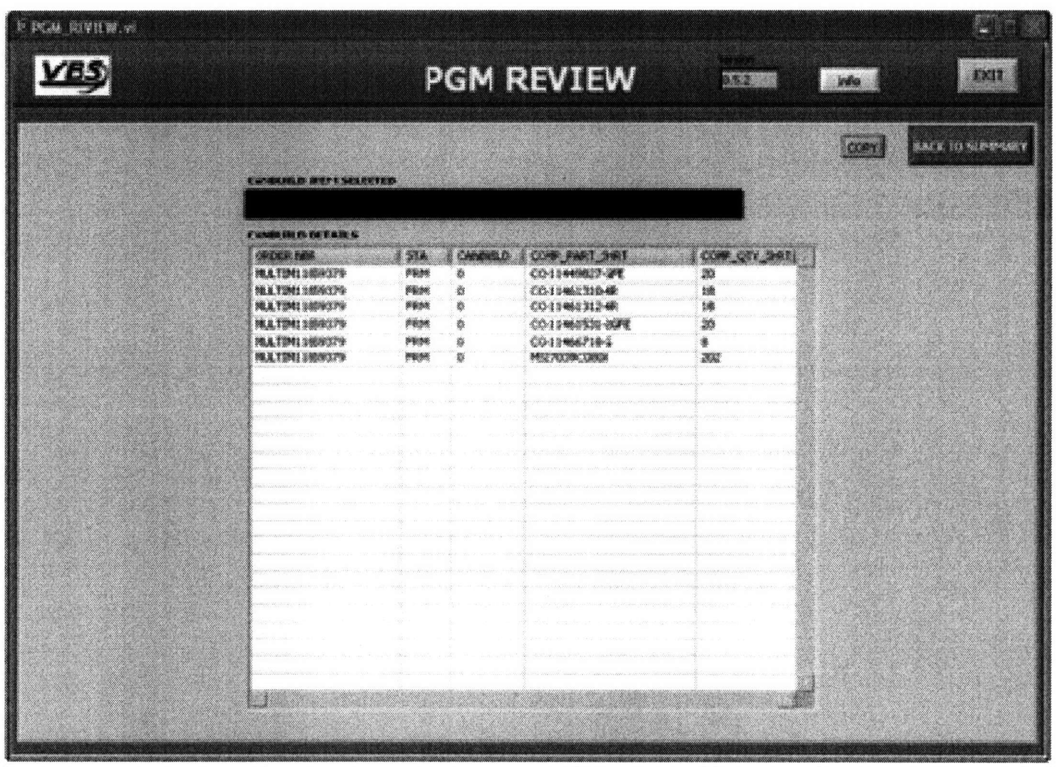

Figure 5-3: Canbuild Drill-Down Details

Similar to the drill-down capabilities of the canbuild row, there also exists drill down capabilities to show the demand of the part numbers for each of the next six months as well as a total of the demands after six months. This screen is accessed by clicking on the rows of CUR_MRP or PD_MRP. As stated earlier, the demands for the upcoming six months tend to stay relatively constant given the nature of this industry; however, the demand number that represents over six months might change quite drastically as seen with the recent jump in Program X's orders.

The screenshot shown below has several other parts (other than the 6 month demand forecast). One of the sections deals with a metric called "OnTimeMRP." Although, the details are covered, broadly speaking, the metric measures the predictability of a part number being completed as well as meeting the demand for the month (includes past due demand). The figure below shows a sample screenshot of the canbuild details.

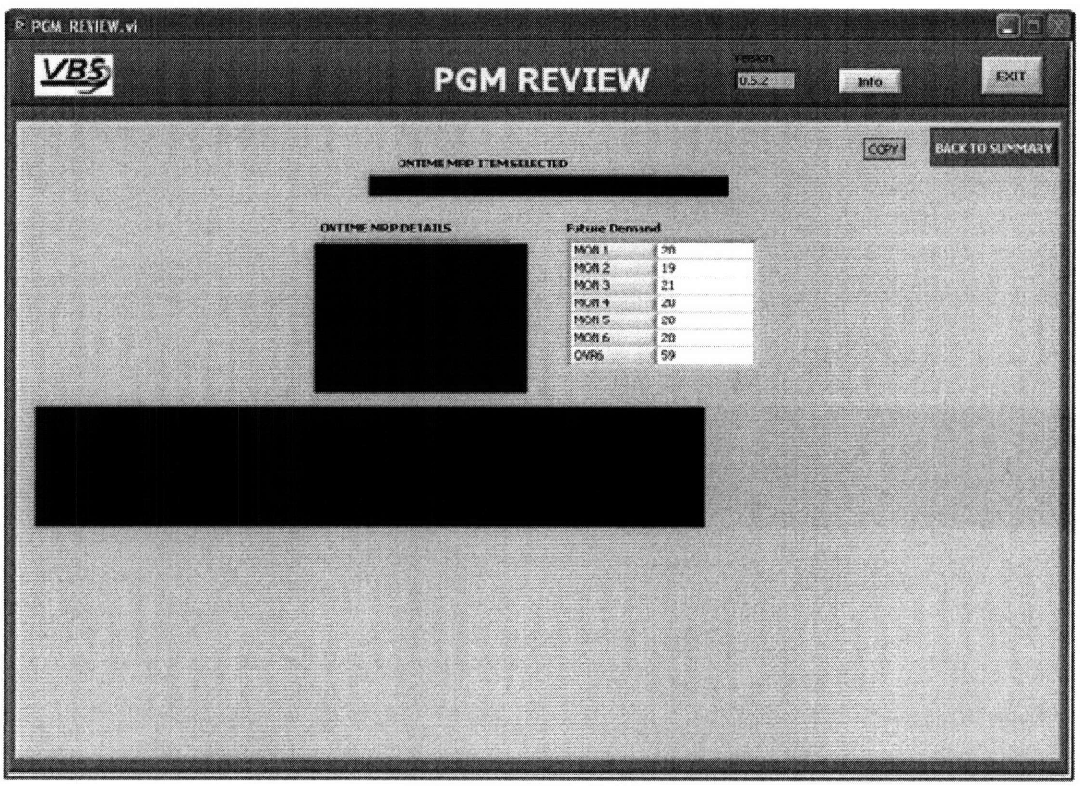

Figure 5-4: Demand Details

Ultimately, the purpose of identifying the bottleneck is also to drive towards a pull system. As noted above, the dashboard can indicate if there is a pull system. After the dashboard was implemented and introduced to the various stakeholders, there was a lot of discussion regarding pull systems, that wasn't being considered previously. This reaffirms that one of the key aspects of introducing change into an organization is to stimulate the thoughts towards process improvement.

5.6.3 Identifying Risks

There are obviously many possible risks that can arise in a manufacturing setting. As stated in section 5.6.1 the stakeholders' risk concerns are regarding "dog items." Those dog items can be further defined into three buckets:

- Age of a part number at an operation and throughout its cycle.
- Budget concerns regarding high k factors; k factor is the ratio of time actually spent on the item (labor hours) vs. the ideal time. Rising K factors can signal an upcoming schedule risk if not mitigated by extra personnel. The intent of k factors is to measure human inefficiency, lack of training, or a high rework condition.
- History of a part number with indication of off-router occurrences.

The following image shows the screenshot of the dashboard with the aforementioned information.

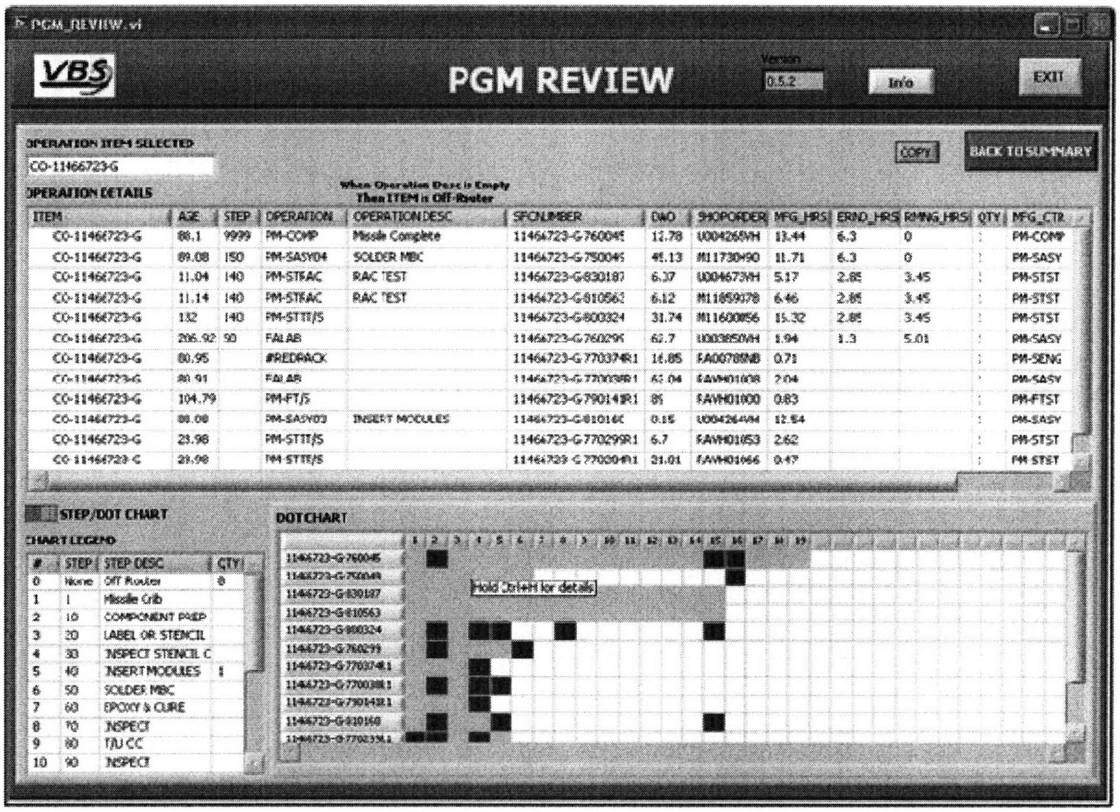

Figure 5-5: WIP Details Screenshot

The above screen is the WIP for one part number. The part number consists of many different serial numbers. Serial numbers (or known at IADC as SFC) are the smallest tracking identification number for a part. In other words, part numbers are always given the same identification at Raytheon whereas the identification code to distinguish one part number from the other is the SFC. IADC uses the terminology SHOPORDER to refer to multiple SFCs geared to one particular order. From the figure above, each row is a specific SFC and has all the associated analytics on the same row.

- **<u>Risk (Aging):</u>** There are two age metrics in the screenshot. The first one “age” shows the accumulated age of a particular item, whereas the DAO (Days at operation) shows the age at the current operation for that SFC. Since we know from the previous section the cycle time of a part number, we can easily tell if an SFC has been aging much greater than its cycle time.

- **Risk (Budget):** The k-factor is simply the MFG_HRS/ERND_HRS. The k-factor becomes important during negotiations with the customer. Program X's PMO can better charge the customer as long as it has accurate information about the k-factor. Consequently, the PMO likes to review the k-factor metric regularly to ensure that the manufacturing budget is running according to plan. In the past, the finance department was the only group looking at the k-factor. Given the increased visibility in the process, the manufacturing work centers are now able to understand the k-factors. This gives the manufacturing work centers a better understanding of the PMO's concerns resulting in better alignment with the strategy of Program X.
- **Risk (Increased Off-Router Occurrences):** From Figure 5-5, there is a graph labeled "Dot Chart" which attempts to capture in a visually pleasant manner the following information:
    - Current operation for a particular item (This is the last "light colored" box. For example, for the top row, we notice that the last light colored box is under column 19)
    - Number of off-router occurrences during a particular operation. In some instances, an item can fail multiple times at the same operation (this is indicated by a number placed inside the "dark colored" boxes)

- The last operation/step before an item went to off-router. This is quite helpful, as sometimes it might indicate that there is a batch of items that keep going off-router at the same operation.

The Dot Chart was a manual chart already being used by the PMO. The chart was created on a daily basis by a full-time employee. However, given the tedious effort required, the full-time employee was only able to create the chart for the highest assembly level part numbers. The frustration regarding the generation of the Dot Chart was clear and after figuring out a method to automate the process, it again helped propel the success of the "PGM_REVIEW" visual dashboard. The Dot Chart instead of being a day old is now presented instantaneously.

The details behind the Dot Chart are also available to the user in the following screenshot.

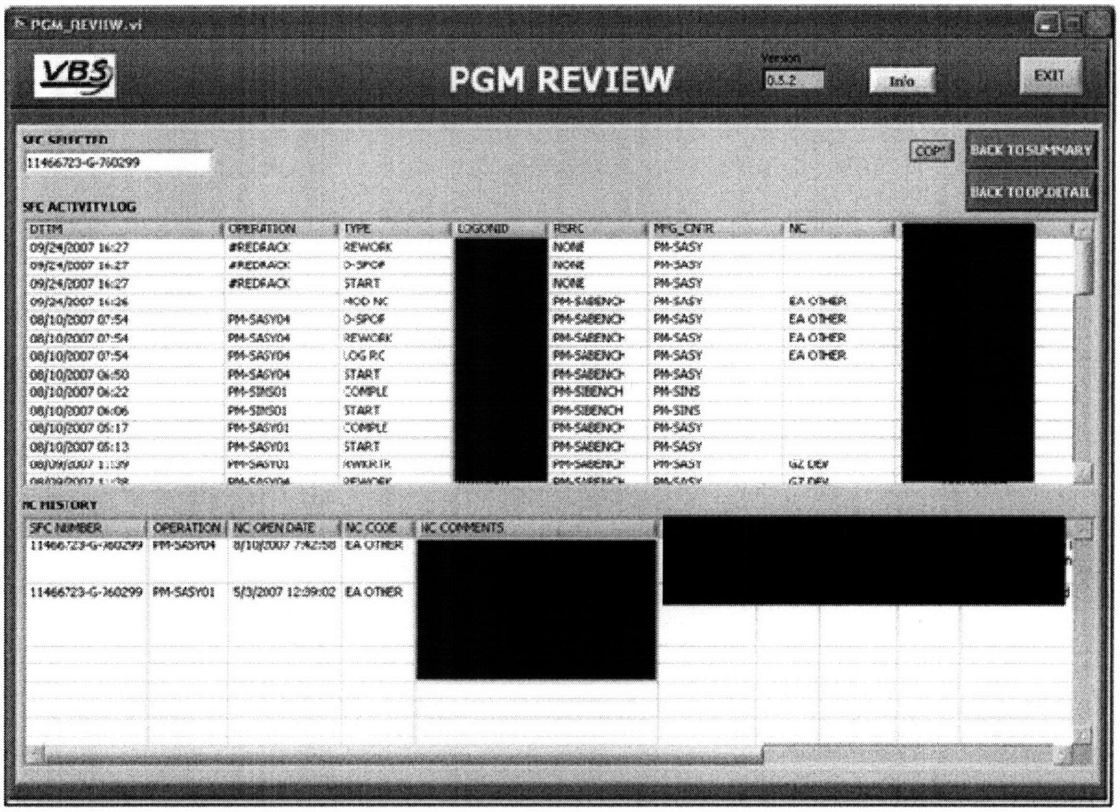

Figure 5-6: Activity Log & NC History

There are two tables shown in the Figure above; the top table represents the activity log of one item whereas the second table represents the non-conformances details associated with that item.

The first table shows every single operation of an item from start to its latest wip status. The information presented includes:

- Time of operation
- Operation description
- Type of operation (rework, start, complete, etc.),
- Name of the operator performing the operation
- Resource used to perform the operation. Resources are the tools and machines used

- Location of the manufacturing work center
- Non-conformance type: The IADC uses a variety of non-conformances (NC) codes to easily identify the type of NC
- Other data shown are specific tracking identification numbers

The second table focuses on the NC details including the comments provided by the operator, the time that the NC was opened for review. The disguised data delves into even more granularity regarding NC issues, which is not necessary for this thesis. However, the key idea behind the above figure is to show accountability. Thus, the stakeholders all have access to the data and can be proactive instead of reactive. In other words, critical decisions can be made sooner to mitigate the risks discussed earlier.

5.6.4 Identifying Opportunities

The main focus of the stakeholders was to meet customer expectations and not necessarily taking the time to observe the Program X process for any type of continuous improvement. This also was due to the fact that the stakeholders always argued that there wasn't enough time for them to both manage the process and improve the process. Thus, one of the key tasks for the solution was to enable the users of the dashboard to have the opportunity to easily assess variability in the process. Before the implementation of the VBS dashboard, none of the stakeholders had access or were actively looking at the variability in the process.

The solution provided currently is able to show the variability and trends of the following:

- Variability in planned monthly production against actual monthly production

- Variability in planned execution time of an operation against actual execution (it is the runtime and the setup time associated with an operation)
- Variability in planned cycle times against actual cycle times (already discussed in section 5.6.2)

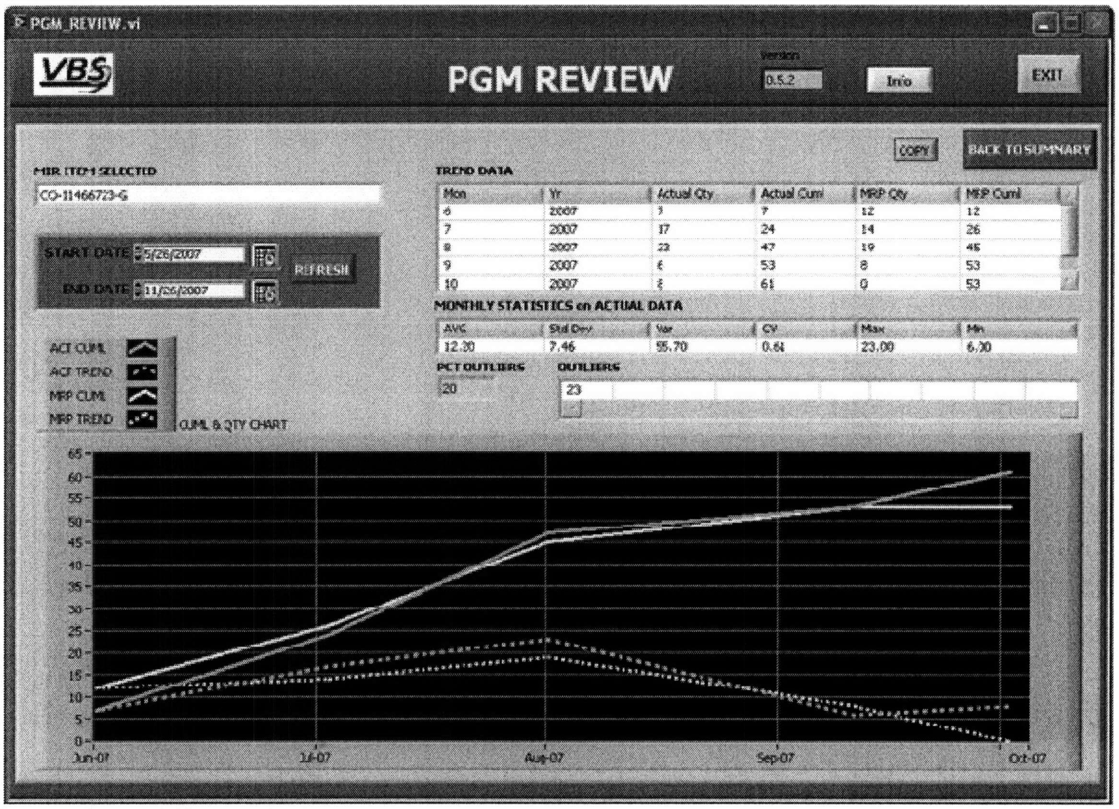

Figure 5-7: Monthly Production Screenshot

From the above figure, we obtain the trend of the variability in planned against actual monthly production. The actual production is labeled on the chart by "ACT CUML" which represents cumulative production and "ACT TREND" represents monthly actual production. The planned production is labeled "MRP CUML" and "MRP TREND." The figure also shows the various descriptive statistics including mean, standard deviation, variance, coefficient of variation, maximum, minimum and list of outliers.

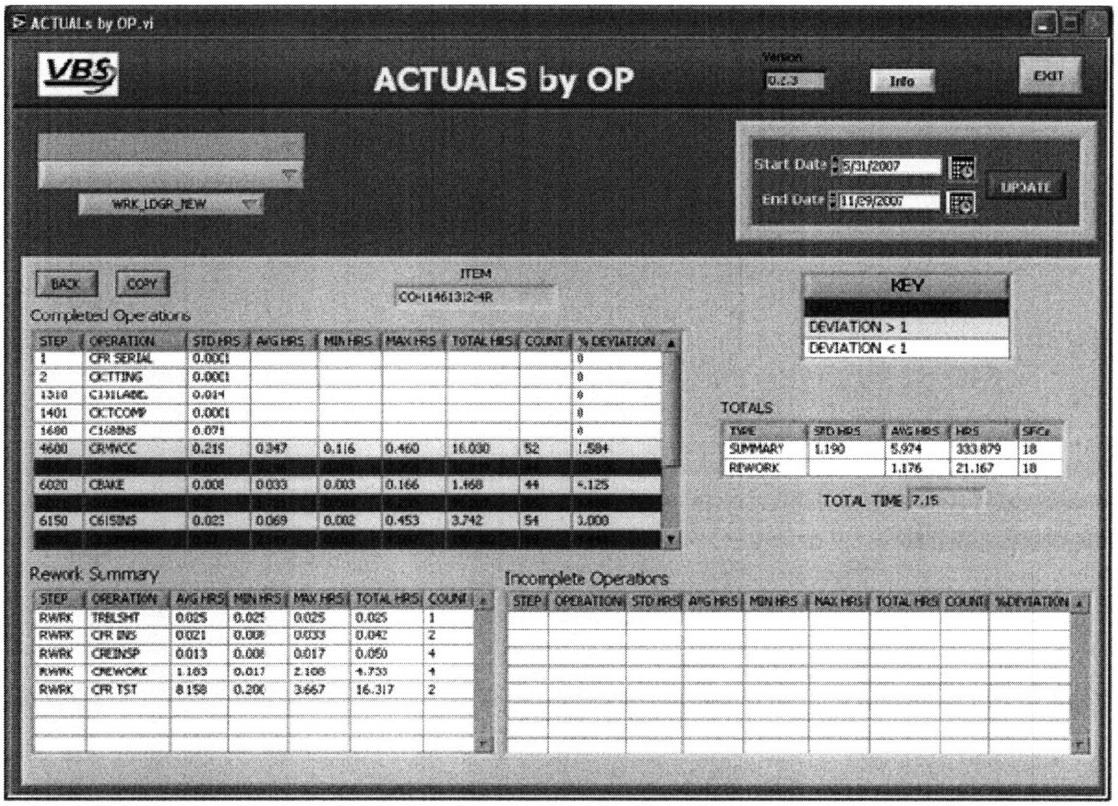

Figure 5-8: Operation Details Analytics Screenshot

If a stakeholder wants to examine the variability between the planned and actual execution time of operations, they can go to Figure 5-8 (which is accessible from Figure 5-5). Figure 5-8 has four tables to help describe the variability of a part numbers various operations. It shows the following information:

- **Completed Operations Table:** Shows the step number, operation description, the standard hours (which is the planned execution time), the average actual hours, the minimum execution time, the maximum execution time, the total hours of this operation (number of items multiplied by actual execution time), the count (number of items that passed through a particular operation) and finally %deviation (refers to the percentage of deviation against the planned time). The darker coloring shows the operations with the largest variability.

- **Rework Summary Table:** Unlike the completed operations table which lists out the "on-router" operations, the rework summary lists out the "off-router" operations using similar analytics to the completed operations table.
- **Incomplete Operations Table:** Same analytics as the other tables but for the "off-router" operations that are not necessarily of the rework type of operation.
- **Totals Table:** This table is a cumulative tally of the rework summary and completed operations table. It provides the descriptive statistics.

After stakeholders observe the operations with the greatest variability, there exists additional drill-down capability in the system to pinpoint the exact dates and people working on the operations with the greatest variability. The aforementioned can be seen in Figure 5-9.

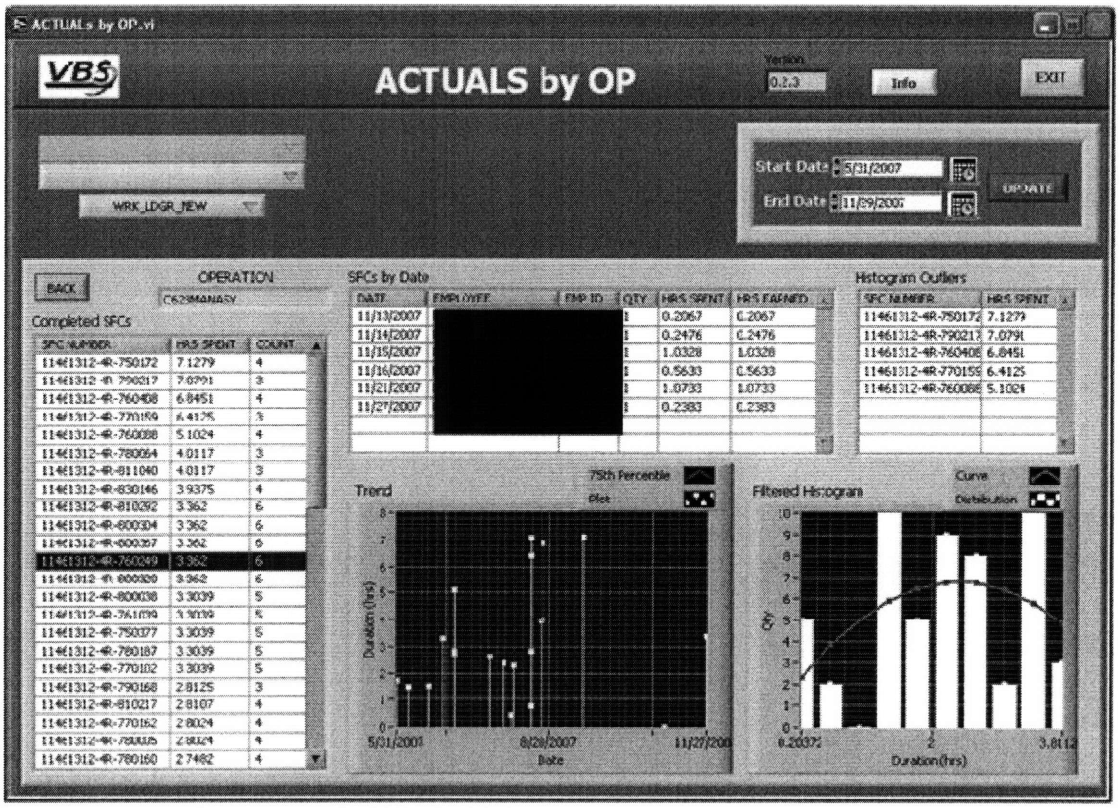

Figure 5-9: Operations Details Analytics Drill-Down Screenshot

Figure 5-9 has three tables and two charts which attempt to provide drill-down analytics after a stakeholder has determined a particular operation that they would like to examine. Once an operation is selected, then the following data is available:

- **Completed SFCs:** Lists out every SFC that has completed the selected operation and provides the actual hours spent.
- **SFCs by Date:** This is a table with relatively sensitive information because it lists the operator by the operation. Clearly, it allows for dialogue between operators and managers to understand the reasoning behind the delay in an operation. However, in some scenarios, there are multiple operators working on different SFCs for the same operation which results in comparative results of efficiency among the operators. Consequently, it might make managers with the wrong

mindset to start aggressive dialogues with their operators. The stakeholders given access to this screen need to know how to use it effectively and not in a manner that might lead to undesirable effects.

- **Trend Chart:** Chart showing the trend of the actual execution time over the selected period
- **Filtered Histogram:** It is a histogram observing the data while removing the upper outliers[7]
- **Histogram outliers:** Shows the filtered data from the histogram chart.

5.6.5 Improving Total Employee Engagement (TEE)

Since one of the key objectives is to instill a process improvement mindset for the stakeholders, it was critical to ensure that projects are solved in groups to enhance the communication, decrease the tense relations and ultimately leverage the knowledge set among the stakeholders. The objectives for improving TEE were to:

- Use visual controls as indicator to easily identify problems.
- Teach Lean principles to employees by creating a method that easily lends itself to using Lean tools to solve problems without specifically saying the tools are from "Lean." The main reasoning was to empower the employees to feel that they came up with the methods themselves.
- Allow easy formation of teams to solve problems and keep record of projects for knowledge sharing.

[7] Upper outlier is defined as $Q_3 + 1.5IQR$, where Q_3 represents the third quartile in a dataset and IQR is the interquartile range. IQR is calculated $Q_3 - Q_1$

Luckily, VBS had established a proof of concept of improving TEE by leveraging another existing dashboard called PROJECT_BOOK (PB). The PB is an interactive dashboard where teams can keep track of a project. All the risks and opportunities identified by using the main tool will need to be eventually documented and approached by a team. However, instead of documenting the projects in a random computer, they can utilize the PB dashboard. In addition, instead of approaching the project without a framework, the PB helps the users to start approaching problems with a six sigma or lean type of framework. The appeal of the PB is that it is a standardized and centralized project tracking dashboard. It also attempts to create several interesting tags to projects as well as introduce several lean concepts.

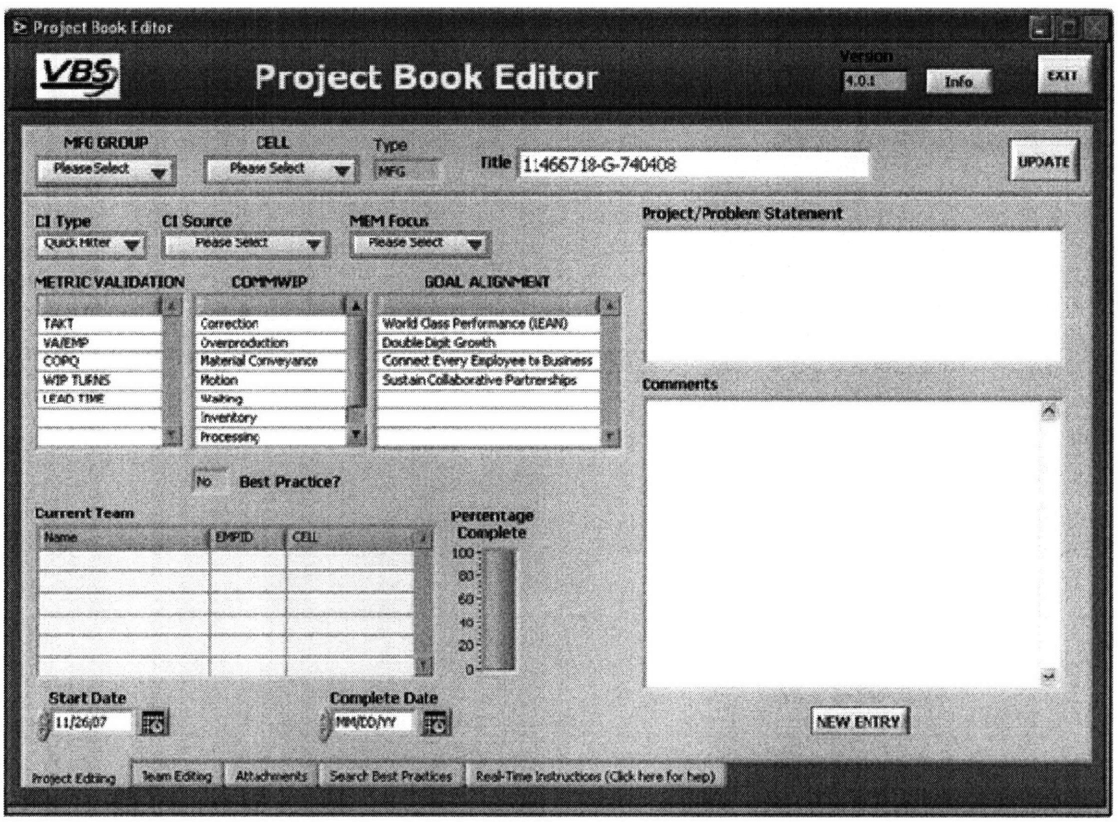

Figure 5-10: Project Book Screenshot

From the figure above, we notice that the PB attempts to tag projects with metric validation, commwip and goal alignment. The metric validation table includes the common metrics used in the Lean and Six Sigma literature such as takt time, wip turns, lead time, etc. The commwip is an acronym used by PB to illustrate the seven wastes identified by the Lean literature including waste produced by correction, overproduction, motion, material movement, waiting, inventory, over processing. Goal Alignment table represents the goals set forth by IADC. In other words, it empowers the employee who enters the details of a project that their work is aligned for the improvement of the company.

During interviews with stakeholders, they all reinforced a common theme that they enjoyed the use of PB because it gave them a sense of working on something exciting and not a "routine" type of work.

5.6.6 Sustainability Plan

The sustainability plan also compasses a management and control plan to ensure the continued success of the VBS dashboard solution as well as the continuous training of new groups seeking to improve the communication between their PMO and manufacturing work centers. The plan consists of:

- **Automated Method for Editing Dashboards:** Another VBS dashboard was created to allow editing of the main dashboard. This translates in leveraging the work already done for Program X towards other programs.
- **Sustainable Development Environment:** Given that the solution provided to Program X was using the VBS architecture it benefits in terms of requiring any new development changes. VBS architecture is based on SQL and LabVIEW, two

off-the shelf applications. In addition, as part of the sustainability plan, a new person was found at Raytheon to help with any incremental changes to the development of the PGM_REVIEW dashboard.

- **Detailed Documentation:** There exists detailed documentation to ensure knowledge transfer of the VBS dashboard. The documentation included:
  - Project motivation, objectives and goals
  - Solution Specifications and alternative solutions considered
  - Recommended solution detail, rationale for choice and potential future enhancements

5.6.7 Continuous Improvement Training Modules Overview

Given the VBS architecture, the dashboard implementation was relatively simple; however, the more difficult part of the internship conducted at IADC was the dashboard deployment. In other words, there had to be a reason to drive change and have all the stakeholders move from an old and comfortable routine to a new method of analyzing data. According to Klein (2004), when trying to pull change, there needs to be a basis for credibility of ideas including basis for legitimacy, basis for relationships and basis for support (Klein, 2004, p. 76).

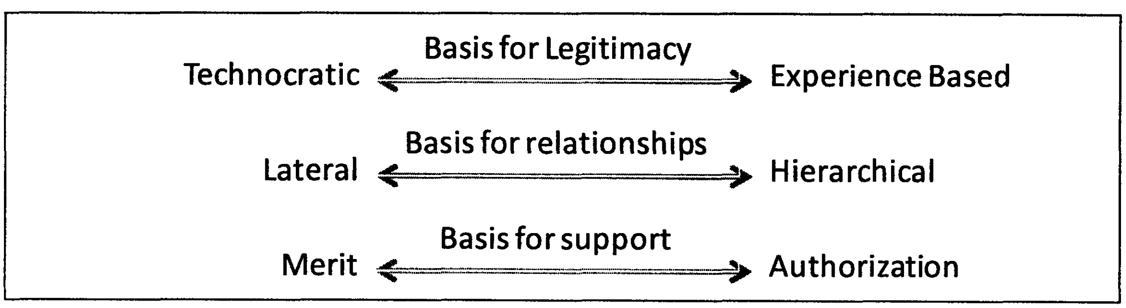

Figure 5-11: Context for Pulling Change (Klein, 2004, p. 76)

Although Raytheon was founded by a group of technologists who highly valued engineering or analytical thinking, Program X's employees leaned more towards an experience based culture where seniority, age and company longevity was the method for establishing legitimacy. Thus, given that the author lacked the longevity at IADC, it was crucial to find another leader in the organization that did in fact have the longevity in Program X. Luckily, as mentioned in section 5.3, the project was co-lead with a R6σ Expert who was a veteran in Program X. The R6σ Expert started out as an operator at Program X and now became part of the management team. On the other hand, when there were concerns about ensuring the data is presented accurately in the dashboard as well as creating a solid technical solution, it seemed very apparent that the stakeholders highly valued the fact that the author was attending Massachusetts Institute of Technology (MIT). Consequently, anytime a technical problem arose, the stakeholders felt relieved to know that an MIT graduate student was in charge of fixing the problem.

In terms of basis for relationships, it was immediately obvious that the manufacturing centers all worked in silos and preferred lateral relationships. This is where the training module became critical to attaining success. All the silos had to feel comfortable that their voice was being heard. Thus, there were several training modules conducted by the author to obtain 1) buy-in from each silo, 2) communicate the latest enhancements to the VBS dashboard and 3) teach Lean principles. Those training modules were the core for establishing lateral relationships.

It did not seem clear whether the basis for support was in terms of authorization or merit, because of the silo mentality. Although all manufacturing work centers are supposed to manage up towards the PMO, thus being accustomed to authority, they argued that changes from management seem to always come and go resulting in the common phrase among the operators "change of the month."

Luckily, there was also the Shingo Prize for Manufacturing Excellence assessment during the author's internship period, contributing to another pull for change. IADC ended up winning the Silver Medallion for 2008 (Shingo Business Prize - Recipients). Consequently, the PMO sponsored the project and declared it as an important process to help in competing for the Shingo Prize.

5.7 Step 6: Achieve (Summary of Author's Contribution)

Step 6 focuses on realizing the gains of the project and ensuring that the change is sustainable. In terms of results they can be classified under both technical and leadership deliverables.

The technical deliverables:

- The main dashboard was delivered to Program X's PMO on October 10th, 2007 with almost a weekly series of iteration and experimentation until end of November, 2007.
- The sustainability dashboard was delivered to Program X as well as four other programs by the end of October, 2007.
- There was a savings of approximately 10% of hours of Program X's stakeholders (~40 total users with 10 power users), allowing stakeholders to focus on more important issues.
- The majority of the stakeholders embedded the new process into their daily activities by December, 2007.

- A sustainable plan was developed and a full-time resource is handling all new development requests. Given that the solution was based on the VBS architecture, a modular architecture was used and is easy for quick development enhancements.
- The entire development process, challenges, and future recommendations were documented.
- A series of new metrics that are more relevant to understanding risks and opportunities were introduced in the main dashboard. The metrics were a combination of leading and lagging indicators.
- Elimination of the data gathering process at Program X resulted in giving back time to the stakeholders to focus on improving the production process to handle the ramp-up in production.
- The dashboard provided a method to analyze problems before they escalate to major concerns, which did not exist in the past.
- By the end of the internship there were approximately 45 users utilizing the dashboards and by March 2008, there are approximately 100 users. Although, the dashboard was targeted for Program X, it now has moved to include five other programs at IADC.
- The author was awarded the title of Raytheon Six Sigma Specialist and a financial savings figure was associated with the author's contribution; however, due to confidentiality reasons it is not disclosed.

The leadership deliverables:

- The project has been acknowledged and identified by senior management as best practice for a stepping stone of driving Lean behavior into a PMO setting.
- A sense of continuous improvement has been instilled in the stakeholders and they are now excited about solving problems instead of constantly simply reporting the problems.
- Stakeholders started to embrace a data-driven approach to solving problems and rely more on actual figures instead of historical experiences.
- There are improved relationships among the stakeholders as they felt more comfortable working as one team and not several separate silos. Although, the aforementioned still has a lot of room for improvement, it is definitely an improvement from the beginning of the project where constant heated discussions were the norm.

6 Recommendations

IADC has clearly matured over the past few years in its Lean Journey. The facility has gained an incredible reputation across Raytheon where towards the end of the internship, the author observed several of Raytheon's business segments including the struggling Space and Airborne Systems (SAS) come seek help and advice from IADC regarding process improvements. Below is a list of recommendations specific to IADC and VBS.

6.1 IADC Recommendations

- Evolve usage of Lean Data and Visual Analytics
    - Combine operational metrics with financial metrics to gain a better overall picture of the health of a program.
    - Create a culture around solving problems using a data driven approach
- Increase usage of leading indicators. The majority of the indicators used are typically lagging indicators and not a good method for anticipating risks and opportunities.
- Migrate to automated data gathering and data reporting systems. In some instances, data reporting could be an employee's only task. VBS is a robust method to achieve the aforementioned.
- Understand the utilization and capacity constraints of the manufacturing work centers. During manufacturing reviews, senior management typically observes each program separately and grades it separately. Consequently, the incentives of the various programs to work together do not exist and are further worsened by

the fact that each program needs to share the resources available at the manufacturing work centers. In other words, since the PMOs do not want to be late to customer delivery dates they add an increasing amount of buffer time to the delivery schedule. In addition, they add another amount of buffer time to the MRP schedule. This is done across all the programs, resulting in unnecessarily creating a sense of urgency, when in fact, there should not be a sense of urgency. Furthermore, manufacturing work centers are always complaining they are behind schedule and that all the PMOs constantly want to "rush" orders. Thus, there is an unnecessary cost that could be mitigated if senior management had the tools to assess utilization across the manufacturing centers. This could be a project for VBS to attempt to obtain a view of all the programs and the relationships of the programs with the manufacturing work centers.

6.2 VBS & IT Recommendations

- Extend the PGM_REVIEW solution to other programs:
    - The pilot solution worked for Program X and by the end of the internship, a total of 4 programs were using the solution. During 2008, a fifth program joined. However, there is significant room to scale the technical solution to other programs throughout IADC
- Improve data infrastructure
    - Although, data is scattered across multiple legacy systems at IADC, there is no central location that has the documentation of the data stored in those systems. In addition, given the tribal knowledge regarding the data stored in the legacy systems, it becomes almost like trying to find a needle in a

haystack when searching for data. Thus, a major contribution would be for the VBS team and the Information Technology (IT) department at IADC to work together and document the data spread across the legacy systems.

- The VBS server contains several duplicated data, thus a cleanup of the databases is critical to ensure appropriate server utilization. Another undesirable effect is that some data tables have become obsolete because the developer who created the initial data table is no longer part of the VBS group.
- Improve communications between VBS and IT. Historically, there has always been a struggle between VBS and IT with regards to control over the data. Senior management at IADC should step in and clarify the roles and responsibilities of both departments. In some cases, there tends to be duplication in the efforts between VBS and IT. However, it might prove useful to have IT manage the data in terms of collection and maintenance whereas VBS manage the analysis of the data in terms of converting data into useful information for decision making.

- Create control processes on the VBS development methods
  - VBS heavily relies on the influx of transient MIT students who have helped VBS over the past three years in intervals of 6 months. However, there are other transient developers who have also helped VBS for a short period of time. Although, the approach minimizes short-term costs, it creates some undesirable effects if there are no controls in place. The

undesirable effects stem from the fact that many of the developers did not properly document the solutions.

- Improve scalability of VBS architecture
    - VBS relies on a limited number of resources and as such caters to a minority of users. If VBS is to become the standard data mining tool, it will need to grow at a much faster pace. Clearly, there will be some financial implications, but it is unavoidable if VBS is to continue its success and reach other areas. The scalability might come in the form of additional full-time resources at VBS as well as providing VBS training modules to help spread the VBS development tools and the VBS culture. Overall, VBS has the potential to become the catalyst that drives Lean thinking and behavior across Raytheon and not only IADC.

7 Conclusion

The hypothesis of using visual analytics to change behavior and improve communication among stakeholders turned out to be a success when applied to the PMO setting. At the end of the internship the author managed to eliminate the data gathering and information reporting function for Program X's employees as well as train them in Lean principles. The data gathering and information reporting function used to take up 10% of the various stakeholders' daily time. By March 2008, there were 100 users utilizing the visual analytics dashboard created by the author. By showing visibility into the production process, the author managed to ease the tensions between the PMO and the manufacturing work centers. Although the financial savings is not disclosed due to confidentiality reasons, the reader can obtain a summary of the benefits from section 5.7.

Although, VBS is a technical solution, it brings a series of Lean principles that when combined with constant training and communication can lead to powerful results. At first, when the solution was being implemented, there was clearly a resistance against change, but once a direction was set by senior management as well as clearly defined benefits to all stakeholders, then it became much easier to break the resistance against change and completely reverse it such that the stakeholders started to embrace change.

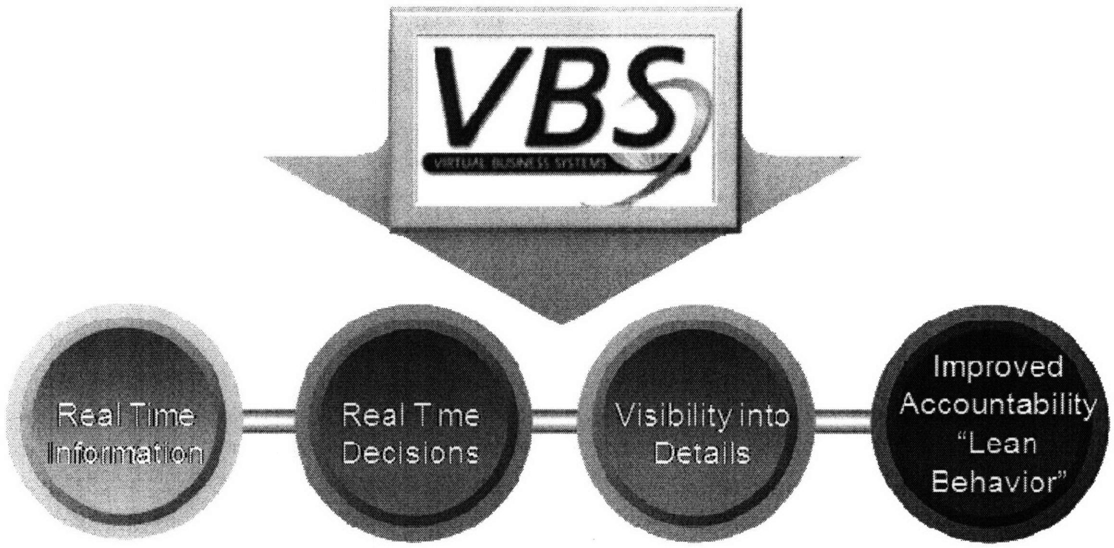

Figure 7-1: VBS Culture

There were several challenges both technical and leadership based, but given enough time, perseverance, and buy-in from senior management, the challenges were eventually overcome. Overall, all the stakeholders were happy with the results as it not only affected more the bottom line (in terms of financial savings), but also improved the relationships among the stakeholders and fostered a culture of community and trust. Ultimately, visual analytics combined with constant communication around Lean principles can lead to financial savings as well as improved employee morale.

8 Bibliography

The Office of Naval Research's Best Manufacturing Practices (BMP) Program. (n.d.). *Best Practice : Virtual Business System - Dashboards*. Retrieved March 19, 2008, from Best Manufacturing Practices: http://www.bmpcoe.org/bestpractices/internal/rayid/rayid_7.html

AGI-Goldratt Institute. (n.d.). *Overcoming Resistance to Change*. Retrieved 2 14, 2008, from Theory of Constraints and its Thinking Processes: http://www.goldratt.com/toctpwp7.htm

Bartleby.com. (n.d.). *Newton, Issac*. Retrieved August 20, 2007, from Great Books Online: http://www.bartleby.com/66/18/41418.html

Davenport, T. H., & Harris, J. G. (2007). *Competing on Analytics*. Boston: Harvard Business School Press.

Day, J. (2007, 10 15). VBS Culture: Driving Lean Behavior. (B. Antoniou, Interviewer)

Deming, W. E. (2000). *The New Economics: For Industry, Government, Education*. MIT Press.

Goldratt, E. M. (2004). *The Goal: A Process of Ongoing Improvement*. North River Press.

Holmes, C. (2007). *The Ultimate Sales Machine*. New York: Penguin Group.

ICMBA. (n.d.). *The BCG Growth-Share Matrix*. Retrieved 3 8, 2008, from Internet Center for Management and Business Administration, Inc.: http://www.netmba.com/strategy/matrix/bcg/

Investopedia.com. (n.d.). *What are leading, lagging and coincident indicators? What are they for?* Retrieved 1 15, 2008, from Investopedia: http://www.investopedia.com/ask/answers/177.asp

Klein, J. A. (2004). *True Change*. San Francisco: Jossey-Bass.

McCaghren, N. (2005). *Enabling Process Improvements Through Visual Performance Indicators*. Cambridge: MIT.

National Instruments Website. (n.d.). *NI Labview Homepage*. Retrieved 11 14, 2007, from NI Labview: http://www.ni.com/labview/

Politano, A. (2003). *Chief Performance Officer*. New York: iUniverse Inc.

Raytheon. (2006). *Raytheon Annual Report*.

Raytheon Website. (n.d.). *Raytheon Company: About Us: History: The Early Days*. Retrieved July 14, 2007, from Raytheon Company: http://www.raytheon.com/about/history/early/index.html

Raytheon Website. (n.d.). *Raytheon Six Sigma Process*. Retrieved January 10, 2008, from Raytheon: http://www.raytheon.com/about/r6s/r6s_process/index.html

Shingo Business Prize - Recipients. (n.d.). Retrieved March 25, 2008, from The Shingo Prize for Operational Excellence: http://www.shingoprize.org/Recipients_Business.cfm

Spear, S., & Bowen, K. H. (1999, September-October). Decoding the DNA of the Toyota Production System. *Harvard Business Review* , pp. 97-106.

9 Appendix A: VBS Copyright

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