

**Digital Factory: Real Time Information System Implementation
in a Traditional Manufacturing Environment**

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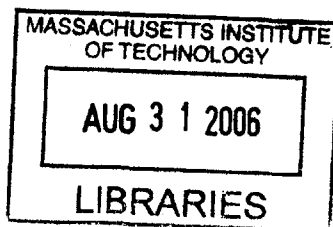
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Abstract

The Internet and emerging technologies such as RFID have been making profound impacts on operations of traditional manufacturing companies. Advances in these fields have opened up possibilities for significant improvements in process, productivity, quality, and communication. The ability for a company to keep up with current technology trends directly affects the company's ability to achieve customer satisfactions, ability to maintain competitive advantages and ability to accomplish its financial targets. Digital factory is a project that Hamilton Sundstrand piloted to investigate how its new 787 component assembly lines can take full advantages of existing technologies. A RFID based prototype solution was developed. Key functionalities include real time work-in-progress monitoring, digitized work instruction display and automated Andon response. The prototype demonstrates that a practical sophisticated infrastructure can be built with widely available equipment and tools. Real challenge in full scale deployment of digital factory will be to identify functionalities that are truly critical to production needs and implement those in a practical fashion so that they can become an integral part of production system.

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Don: This has been two amazing years. Thank you for everything.

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Chapter 1: Purpose and Structure

The following are key points in this chapter:

- A narrative about the purpose of this thesis
- An overview of the structure of the thesis

1.1 Purpose

This thesis is to provide readers with a close look at implementation of a digital infrastructure prototype that assists operational and management activities on assembly lines for Boeing 787 Air Management System at Hamilton Sundstrand. Features of the digital prototype include real time work-in-progress monitoring, digital work instruction display and automated Andon signaling and response. How RFID will fit into future assembly line and potentially the entire value chain is investigated. The thesis discusses prototype architecture and implementation issues. This thesis further explores framework and methodologies that can help decide optimal implementation strategy for such infrastructure in a much larger scale.

1.2 Structure

This thesis is organized in the following manner:

Chapter 1: A description of the purpose of this work, and an overview of the organization of this thesis.

Chapter 2: Background on information technology trends in manufacturing. Introduce the concept of digital factory and overall project background. A brief overview of Hamilton Sundstrand, where the experiment was conducted

Chapter 3: Talks about what digital factory really is. Introduce an example of an ultimate digital factory that makes the entire supply chain activities highly visible to everyone. Introduce important criteria that are used to define the scope of the digital factory prototype.

Chapter 4: An overview of enabling technologies used in the prototype.

Chapter 5: Documents key implementation details in this project based. The chapter focuses on relatively high level architecture instead of full blown implementation details such as software programming constructs and database layouts.

Chapter 6: This chapter provides an analytical framework for full scale digital factory implementation strategy. The difficult part of task is not figuring out technical solutions to get certain features to work. The real challenge is to understand and decide which features and functionalities are important to operations. Implementation strategies will heavily depend on non-technical elements such as organizational structures and supply chain configurations.

Chapter 7: Summarizes findings and recommends future research areas.

Chapter 2: Introduction

The following are key points in this chapter:

- An overview of current trend in operations management
- A brief description of digital factory
- An introduction on Hamilton Sundstrand

2.1 Current Trend

U.S. manufacturing companies across all industries are under increasing pressure from competitors in oversea low-cost regions. In order to stay competitive, many U.S. firms have invested heavily to improve efficiencies and to reduce costs. The Toyota Production System model and the lean concept have made profound impact on current revolution in U.S. manufacturing. Companies are aggressively pursuing lean strategies to transform their operations [Levinson, Rerick, 2002]. However, such transformation is a very complex and challenging process because lean implementation impacts literally every aspect of business including activities on production lines, procurement, scheduling, material flow, inventory management, information technologies and integration, human resources, and organizational structure.

This thesis is to explore one particular aspect of lean manufacturing. The fundamental objective of lean is to achieve efficiency and highest quality at lowest cost for a given production system. A critical part of implementing lean is information management and technological infrastructures that would make such management faster and easier. This becomes more relevant when the lean concept is applied to the entire value chain that would include your customers as well as your supply network [McClellan, 2003]. Real-time information flow and system optimizations would help organizations drive down costs and improve performance [Arnold, Chapman, 2004]. Our research project is to investigate practical ways and strategies for implementing such real-time information/control system.

Many world class companies have been investing heavily in integrating next generation information technologies into their business operations as a mean of maintaining their competitive advantage. For instance, Wal-Mart is pushing very hard for a standardized goods monitoring technology to reduce inventory management cost. It will be interesting to see how traditional manufacturing companies can take advantage to improve their bottom line.

2.2 Digital Factory

Advances in information technologies in past ten years have dramatically improved the availability of real-time information. Computers have brought significant gains in productivity to U.S. manufacturer [Gunn, 1981]. The emergence of the Internet-based applications has really changed the way we conduct business. The challenge for many businesses now becomes how to leverage available technologies and tools to build and integrate an information system that addresses real operations needs at a reasonable cost within a short time period [Macbeth, 1989]. In addition, the system needs to be simple, user-friendly, flexible and easy to maintain.

Our project is called digital factory. Our goal is to implement prototype infrastructure and investigate ways technologies that help improve efficiency and productivity in a traditional manufacturing plant.

The concept of digital factory, however, varies wildly depending on whom you ask*. Different people with different backgrounds will have very different ideas about what exactly would constitute a digital factory to them. The first step in our project is to collect and understand different views. The success of the project depends on our ability to integrate a wide spectrum of visions into a unified one. This also makes it difficult to define a clear scope for the project because it seems that the digital factory will need to serve everyone. In Prototype Implementation, we will discuss the criteria that we used to narrow down the implementation scope.

2.3 Hamilton Sundstrand

Hamilton Sundstrand is a leading global supplier of aerospace and industrial products for both commercial and military applications. It also provides extensive aftermarket repair and maintenance services. The company has operations in various places across the country, including in California, Illinois, and Connecticut. Hamilton Sundstrand is headquartered in Windsor Locks, CT. United Technologies Corporation (UTC) is its holding company. Ticker symbol of UTC is UTX.

The Windsor Locks' facility manufactures detail parts including blades, rotors and segment gears for a wide range of aircrafts. The site has classic high-mix-low-volume operations with over two thousand end items being produced annually. It has limited amount of assembly work for air management modules on small and medium size airplanes. Almost all work is performed in traditional stationary cells or work benches.

Hamilton Sundstrand is now going through a major transformation at two levels. At the product level, the company wants to improve its assembly capacity. At the operations level, Hamilton and UTC have been very active and persistent on adopting lean principles to improve productivity and quality and to further lower costs. The successful bid on Boeing 787 provides a natural transition and an opportunity for Hamilton Sundstrand to expand its existing assembly capability, which in turn opens up new fronts for operations improvement.

** This is based on various conversations with different team members and parties at Hamilton Sundstrand.*

While the Boeing 787 project presents a huge business opportunity to Hamilton, it is also a tremendous challenge because of its large scale, complexities, aggressive scheduling, steep learning curve and cost requirements. The current infrastructures for assembly activities at Hamilton will need to be revamped in order to meet new demands, particularly in the area of information management and real-time system optimizations. The digital factory project is a part of overall effort of preparing Hamilton Sundstrand for the 787 contract.

In response to the demanding 787 contracts, management of the Windsor Locks plant, the site at which assembly lines will be installed, formed a dedicated team under the operations for the task. This is a cross-functional team of which our digital factory team is a part.

Chapter 3: Our Vision

The following are key points in this chapter:

- A discussion of what “digital factory” means
- A overview of an ideal digital factory and a more practical one
- Features that the prototype will need to support

3.1 Revisit the Concept

So, what exactly is a digital factory? What kind of information technologies should it use? What much will it cost? How long will it take to recoup the investment? Will it be practical? What kind of organizational impact will it have? What about integration with legacy IT infrastructure? Is it robust? How will it be vertically integrated with our suppliers and customers?

The list of questions goes on and seems endless. We definitely won't be able to address every single one in our project. The goal of our project is to construct a simple but complete prototype that will not only serve as proof-of-concept, but also can be used and tested in real production situations.

3.2 The Ultimate Digital Factory

The concept of digital factory is related to but extends beyond computer integrated manufacturing (CIM). CIM usually refers to the pervasive use of computers to design the products, plan the production, control the operations, and perform the various business related functions needed in a manufacturing firm [Groover, 1987]. Digital factory is about applying these computer technologies to the entire supply chain because this is becoming a requirement by both customers and suppliers [Langenwalter, 2000].

Part shortage is a very common problem that plaques every day production and scheduling. It can cause production line to stop and delivery date to be missed. This is especially an issue when every vendor in the supply chain wants to carry only minimum levels of inventory. One way to cope with a costly part shortage is to increase supply chain visibility.

Now let's imagine that you are the production manager in charge of 787's Air Management System (AMS). The entire production system has been modeled based on lean principles. Parts are coming, or rather “pulled” from supplier or warehouse, in a just-in-time fashion. Each module and sub-module is built just-in-time to be fed into next assembly. Inventory is very low. The one-piece-flow assembly lines are humming at a carefully calibrated pace to meet Boeing's demand just-in-time. You can see where

exactly everything is on your big LCD screen. The entire production system is under your finger tips and you expect everything will be delivered on time. All of sudden, you see a green indicator on your computer screen turn into flashing orange. A compressor for the AMS did not register with RFID reader in your supplier's local staging warehouse within expected time frame, which means it didn't arrive as scheduled. You want to see what happens to the compressor, so you move your mouse and click on the flashing orange indicator. A little hourglass spins for a few seconds and your screen is switched a different screen with detailed status information of the compressor. While everything looks good, an alarming red spot catches your attention. One click on the red spot, it shows that the supplier had to delay the shipment because of a quality issues they are having. There are pages of technical details on what the issue is, but most importantly you see a popup indicating that the supplier has called for all-hands meeting that includes Hamilton Sundstrand as well as Boeing (who is also watching the same screen that you are) because they think the matter is serious enough to warrant a meeting. You quickly switch to Microsoft Outlook and see a meeting has been scheduled and waiting for your reply. It looks that high level managers and VPs are all invited.

This example illustrates an imaginary scenario in which a production manager is notified of a problem that could potentially cause schedule slip. The most important part of the story is that stakeholders from the entire value chain have been notified almost instantaneously when the quality issue became apparent in upstream almost without human involvement. Digital factory enforces people to act quickly and early on potential "show-stopper".

It would be great to eventually have such a system capable of monitoring production progress and sending out appropriate action commands to keep things in order. But the fact is that we probably won't ever be able to develop such a system in a cost-effective fashion. However, this futuristic system provides a good vision that will guide our project development.

3.3 Frontline Digital Factory

The project explores a limited but feasible scope of the digital factory. For instance, integration with external company's IT network and with Hamilton's own legacy systems can be a very difficult and time consuming process. For our project, we will need to start with things we have direct control over. Specifically we will focus our attention on "frontline" portion of the digital factory. This refers to infrastructure that directly supports operations, activities and management on production lines.

We will implement the following five features because they had been selected by the project team and management before the project started. These features are considered important for future assembly lines.

Monitoring/Tracking – the ability to track and monitor parts and work-in-progress are the building blocks of a digital factory. It is not only important to immediate management needs, but also to long term adjustment and optimizations.

Reduce/Remove paper – extensive paper trails have become an increasing burden to management. For instance, all quality and test data are recorded with paper and pencil. This makes any sort of statistical analysis prohibitively expensive and impractical. Hence we are not fully utilizing available information. In addition, inaccurate and out-dated instructions and work sheets is a common problem due to lack of an efficient revision management system.

Notification/Alarm – quick surfacing and revealing of problems on the assembly line are essential to resolution enforcement and damage controls. In the current system, notification is not standardized and there is not enough enforcement.

Visual/Transparency – one center piece of the digital factory is visualization and operation transparency. This is also key driver for other features such tracking and notifications. High transparency will significantly ease management and increase accountability and predictability.

Data Processing/Report Generating – data processing is just as important as data collection. The ability to perform critical data analysis and generating appropriate summaries is another motivating factor for the development of digital factory.

Chapter 4: Technologies Overviews

The following are key points in this chapter:

- Review of technologies involved in our prototype

4.1 RFID

RFID – is emerging as a leading technology poised to replace the traditional point-and-scan laser based scanning devices. It is becoming increasingly popular in fields such as shipping and package delivery services in which traceability of parcels or items are crucial to their business. RFID is also finding success in the retail industry and is expected to make major strides in the near future in both traditional and online businesses such as Amazon and Wal-Mart. The basic idea of RFID is not really fundamentally different from that of the old-fashioned bar code with laser. Items of interest are installed with either passive or active tags which will be detected by a reader. What makes RFID unique is that it uses radio signals instead of laser light to locate tags. This subtle technological difference is what makes RFID the preferred technology. Radio signals differ from bar code laser scan in four ways. First, it is not nearly as directional as a traditional laser pointing device. If designed and positioned correctly, radio antennas can cover an area of considerable size without human involvement. Second, a radio signal is not blocked by walls and structures the way light laser is. Third, RFID technology is much better at picking up and tracking multiple (hundreds or thousands) targets simultaneously. Fourth, RFID introduces the possibility of “smart” or “intelligent” tags which are powered and active. This feature makes history recording possible and is very useful in the grocery industry in which the history of environment produce goes through actually matters. More and more manufacturing and operation based companies are now looking to use RFID technologies to facilitate their material flow and supply chain management.

4.2 Data Network

A data network is the backbone that carries all the information. While in a regular office environment the Ethernet has become synonymous to data network, it is not so simple in the manufacturing world. Ethernet has certain characteristics that are not suitable for the demanding manufacturing world. For instance, Ethernet has latency problems. In the simplest terms, information can be and will be delayed depending on network load. The worse thing is that the delay is not predictable. In an industrial application in which precise timing is crucial to the system control and synchronization, Ethernet can be problematic. Also, Ethernet makes the best effort to deliver data but without any guarantees. In order to deal with these issues, computers that connect to Ethernet have extensive networking software to overcome these shortcomings to establish reliable and synchronized connections. However, not all devices have the capacity of a full-blown computer. For instance, a simple pressure sensor simply does not have any capacity for

sophisticated software. This will require the sensor be controlled by a computer through serial or parallel ports. This kind of configuration in general is not very flexible and scalable due to requirement of computer.

Three types of data networks are commonly used to support industrial applications, DeviceNet, ControlNet, and Ethernet I/P (with I/P stands for industrial protocols). DeviceNet supports smaller equipment and device such as sensors. ControlNet usually is used in a more complex setting, such as automobile assembly line where synchronization and controls take precedence. Ethernet I/P is relatively new to the industrial network family. It's a variant version of Ethernet designed to address real manufacturing needs. Ethernet I/P is more versatile and is expected to replace both DeviceNet and ControlNet in the future. The other advantage of Ethernet I/P is that it is compatible with Ethernet, hence easier to convert to.

Also, this project requires wireless network. We believe that ultimate network for the assembly lines are wireless Ethernet I/P.

4.3 Software

Software/Programming – a project like this will have fair amount of software design and programming. In our project, the primary programming language will be Visual Basic. Visual Basic is developed by Microsoft for its Window's platform. While it is not an ideal candidate for large scale development, it is an excellent tool for quick and small development and prototyping. The other advantage of Visual Basic is that it is relatively easier to find programmers for it. In our prototype, we will need a small database that will serve as data repository. Again, we will use Microsoft product suite because Windows will be our primary platform. We choose Access because it is simple and easy to use. Furthermore, we already have the license for it. In the real production system, we imagine that the backend database will be either SQL Server or other more industrial strength applications from Oracle or Sybase.

There is also significant amount of software work needed for setting up RFID antenna. The programming language for antenna configuration and control is proprietary.

Chapter 5: Prototype Implementation

The following are key points in this chapter:

- Real-time Work-in-Progress Tracking
- Digital Signage/Digitized Work Instructions
- Andon Response System
- Data Collection

There are a number of major features and functionalities built in our Digital Factory prototype that we would like talk about. While some might not be eventually integrated with final assembly lines, we will still see parts of these features and will also help us build up necessary knowledge and experience.

5.1 Real-time Work-in-Progress Tracking

Real-time monitoring of production status of modules such as Air Management System (AMS) is one of the features that will likely be required by Boeing as they continue their effort in improving their overall supply chain's visibility.

The new assembly line for AMS will be a pulling chain moving line with its pace calibrated based on just-in-time delivery schedule. The line should always be moving during scheduled and overtime shifts. Since the purpose of a moving line is to set a strict production pace and to enforce streamline work with an emphasis on minimum rework, once an AMS is rolled onto the line, in theory it should never has to be moved back. It always travels forward. Therefore, we can use the position of work-in-progress AMS to indicate how much work has been performed on the AMS.

In our prototype, this functionality is implemented with the following setup. The assembly line will be somewhere between fifty and seventy feet (estimated). We attached about five to seven RFID tags with about 10 feet in between each (See Figure 1). The tags are small and flat. They are contained in customized plastic case which then will be attached to the floor next to the track. We mount a RFID antenna at the bottom of our self-powered moving cart with its receiving surface facing the floor. As the cart moves along the track, the antenna will move over the tag and detect its presence. Each tag is magnetized with a unique index number. Each tag will represent a unique location on the line. In future implementation, the tag will be associated with production milestones.

It needs to be emphasized that due to the limitation on the RFID antenna and other hardware we have, the RFID equipment is being used almost as a laser scanning device. This is definitely *not* the case with RFID antennas in general. Laser based technology could have been as effective in this prototype, but we would loose physical configuration flexibility with tags and scanning devices permanently mounted in fixed locations.

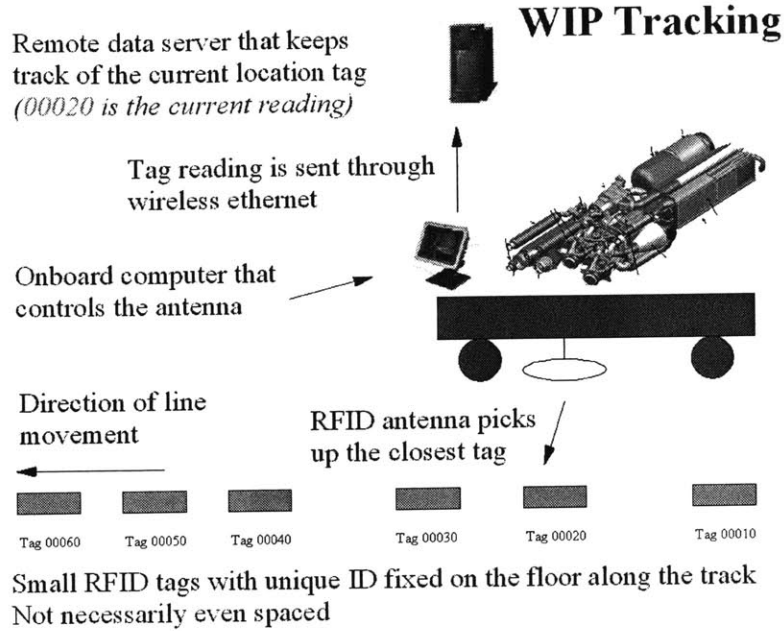


Figure 1: Power Cart with Antenna & RFID Tags

At the backend, we will have a database that is constantly updated by the computer that controls the RFID antenna. This database will be accessible to a variety of applications that will use this information. In our prototype, we have a small software program written in Visual Basic that runs on desktop computers. This program constantly polls on the data table and display the information on the screen (see Figure 2). The significance of this relatively simple setup is that we can easily deploy the same software program at Boeing in Seattle or Chicago. Once appropriate network connection is established through firewalls for respective companies, our customers can easily monitor the progress as well as we can here in Windsor Locks.

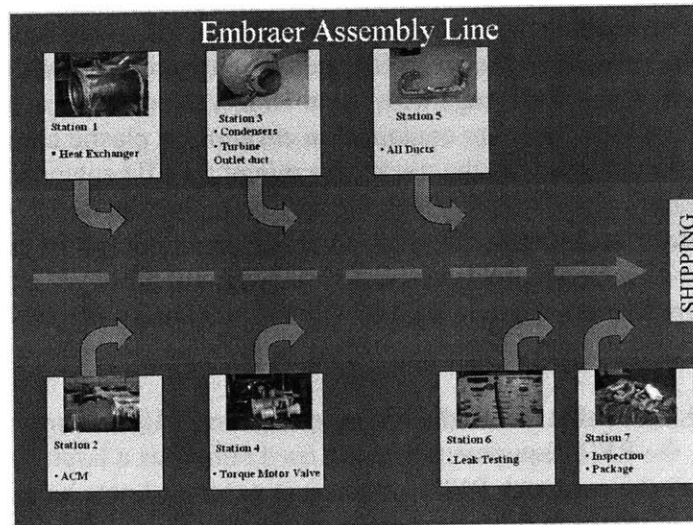


Figure 2: Virtual Process Monitoring

There are a number of implementation issues. First, programming and controlling a RFID antenna, depending on what antenna systems you get, can have a really steep learning curve as it will likely require working with proprietary programming language. Oftentimes, these programming languages are not well documented. Understanding exactly how everything works can take up to weeks. Second, the detail information management and flow between the database and client applications will need some time and trials in real production to understand. Our customers, internal or external, might have different requirements or change their requirements on what they would like to be visible. In our prototype, we are only showing the position of work-in-progress AMS. It is not inconceivable that our customers might request to see which operator is working on the line. Keep in mind that the database will collect a wide range of real time information from production. For instance, test data can also reside on the same database server. It is up to Hamilton and Boeing to agree on what level of information should be visible.

5.2 Digital Signage/Digitized Work Instructions

The position of a work-in-progress Air Management System on the assembly line can be used for work-in-progress monitoring. It can also be used to cue automated display of work instruction sheets. Digitized work instruction sheets are displayed on large size LCD for operators to see. The digitized instructions will be in PDF or PowerPoint format. In our test run, we have both. A typical work instruction book can be anywhere between thirty and ninety pages. So the basic the idea is have these page displayed automatically matching content as the work-in-progress piece moves down the assembly line. The program that controls the display will decide what pages to show and for how long based on the combination of time elapsed and position of the AMS on the assembly line. Figure 3 shows an example of what it would look like on a digital screen.



Figure 3: Sample Page from Work Instruction Book

In our simple setup, again, we will have a computer program written in Visual Basic constantly polling on the database which contains the location information. The program then in turn will instruct PDF Reader or PowerPoint to move to certain page number based on that location information. Pages will be displayed in full screen mode. The Visual Basic application also needs to keep an internal timer for pages that are not cued by RFID tags. Usually in between each RFID tag, there can be anywhere between ten and twenty pages of instructions to be displayed. So imagine there are 10 pages of work instruction between two RFID tags. We know that it would take roughly five minutes or 300 seconds for the moving work-in-progress to travel the distance between the two tags. Then each page will be given about 30 seconds of air time. Of course, duration for each page will be adjusted based on the complexity of the work procedure. The position factor overwrites the timing factor. For instance, if one page is still in display but for some reason and the controlling program detects that the moving work-in-progress has registered with the next tag, the program will switch the display according to the tag.

In our prototype, we have a table that maintains duration time for each page of a work instruction book. The VB application uses this database to obtain the duration parameter.

The concept automated work instruction display is based on the premise, or at least partially, that operators are doing work exactly in the order of demonstrated by work instructions and do not jump ahead or go back in procedure at all. This could serve well as the eventual goal for our assembly lines, but hardly a reality in today's operations. Hence, some modifications are necessary in order to make this prototype realistic and practical. The digital display can function in two modes, automatic and manual. We have just discussed how it would work in the automatic mode.

We provide an interface for operators to switch instruction display to a manual mode. Once in the manual mode, the operator can easily navigate through pages as they do with physical copies. This is useful because before the assembly process becomes mature, we will expect some amount of "re-work" which will require operators to go back and forth on instructions. This display can also be switched back to normal automatic mode through the same interface.

Digital work instruction is to address two specific problems on the assembly line. First it introduces the possibility of reducing or eliminating uses of advanced copy, which is a copy of instructions that has been modified by mechanical engineers and used by operators, but has not yet been registered with the central document repository, the Engineering Records. The reason for using an advance copy is that it will usually take at least a few days or even weeks for the actual changes to be merged into the versions in Engineering Records. Waiting for the official release does not bode with production needs. In order to expedite the process, engineers usually issue an advanced copy to the floor and then update it with the Records. This non-centralized approach allows possibility for mistakes because operators and manufacturing engineers can sometimes be out of sync, especially with frequent changes and multiple instruction books. Operators might need to spend more time to ensure his copy is most up to date. With digital displayed instruction, there is no physical copy to be updated and any changes will be

instantly reflected to the shop floor. This can spearhead improvement in the way Engineering Records handles the version control.

Second, the digital display is to provide quick cross reference capability that is specifically requested by line operators. For our prototype, we will have PDF and PowerPoint based static content for display. But the real appeal of having a digital medium is that it opens the possibility of interactive display. One common request from operators is that they would like to be able to quickly cross reference check on tools that they need for the job. Usually it would take them quite some time to figure out what tools they need. Now we can imagine that instead of PDF or PowerPoint, the content on the screen is touchable and functions very much the same way HTTP web page does. Operators can simply touch a link which would show detailed tool requirement. This is of course not limited to tool reference, but any kinds of cross reference in general.

5.3 Andon Response System

It is not possible to build a production system that never stops and never have any problems. The real challenge is how to respond to events such as part shortages, accidents, quality issues and scheduling conflicts in an organized and timely fashion to enforce swift resolution.

First and foremost, we want to increase the visibility of problems on assembly lines. If it's a problem that no one knows about, then it won't be handled until very late into the process and usually it would be very costly. This is as much a technical problem as a political and organizational one. Information flow from bottom of an organization to top is usually filtered and screened (by choice or accident) so that good news typically surfaces to the top and "bad news" just simply remains at the bottom. In our vision of digital factory, we will want information to flow both ways without any hindering and interference.

There are two components in our Andon System, Andon display and notification. Andon display is a kind of visual management that relies on the combination of traditional Toyota three color Andon stack lights and internet based on virtual Andon lights emulated by computer programs. Notification is a collection of mechanisms we employ to enforce resolutions.

Andon display in our digital factory would have three levels, which is summarized in Figure 4. First is the traditional stack lights installed for each assembly line. The light can stay on green, orange, or red, or a combination of any three. Green means that production is going well without any hitch; orange means that there are problems being worked on and it has not yet made impact on scheduled delivery (internal and external); red means that problems can not be fixed within allowed time frame and it will or has made impact on scheduled delivery. These lights are for operators, engineers and foremen whose locations are within close proximity of the assembly line. The light's

placement will be such that people who directly work on or support the line can see clearly from the shop floor how the line is performing.

The second level of Andon display will be a large all encompassing Andon board(s) that strategically placed in the factory. Its target audience is for everyone on the shop floor. The idea is that someone can just glance at the board and quickly read all the vital signs for all assembly lines. For instance, one can see if how many a specific module has been built for the day; whether or not the production is behind or ahead; how much overtime will likely be needed; is delivery (again internal and external) likely to slip. Again, the goal is that for anyone with reasonable operations knowledge at Hamilton can easily tell what's going on in the factory.

The third level of Andon display is what we believe the real value added by Digital Factory. Everything that we can see on the shop floor, including the small stack lights and the large Andon board, can be seen from anywhere in the company, or for that matter, anywhere in the world through the Internet. The state of these stack lights on assembly lines are recorded in a database real time. As a matter of fact, this is the database that the Andon boards use to display all the information. This database has information pushed to it by individual computer that controls individual stack light for each line. In our prototype, we have a small program written in Visual Basic, which polls the database periodically to bring up-to-minute information to user's screen.

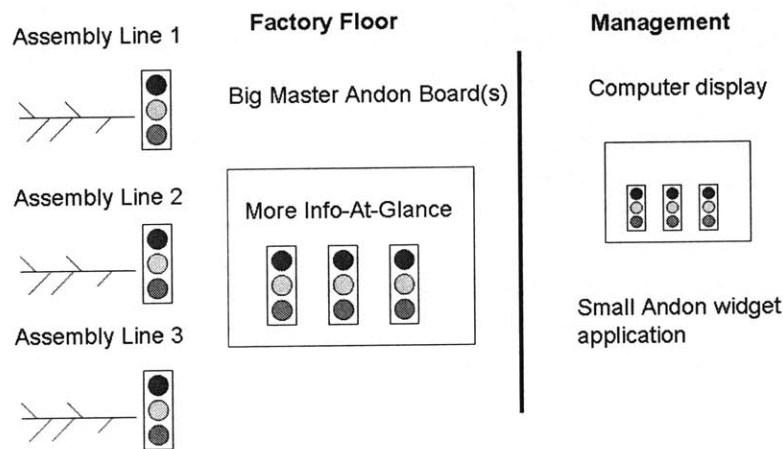


Figure 4: Three Levels of Andon Display

Visual alone is not enough to enforce resolutions on the assembly lines. Additional signaling mechanism is needed in order to reach specific individuals for immediate actions. Emails and pages are effective and non-intrusive ways of pinpoint responsible parties. They are not to duplicate what Andon boards do, but rather to provide

complementary functionalities. For example, they can reach people who are not physically present in factory. Figure 5 depicts a hierarchical signaling system in which an event or exception will eventually reach upper management if the problem can not be properly resolved within allowed time frame. The basic idea is to create a sense of urgency with automatic signaling system at each level, and yet still to give sufficient amount of time needed to handle normal problems so that upper management will only be notified of issues of significant magnitude. The buttons that operators can access on the touch screen are in blue.

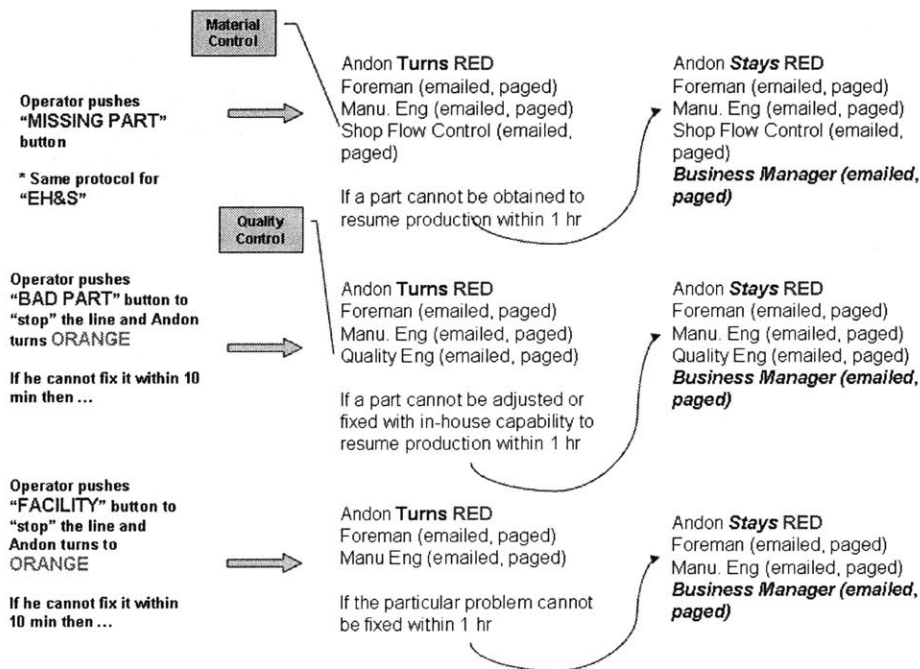


Figure 5: Andon Notification System

This simple signaling system in Figure 5 has timers that would register each event and escalate notification levels as needed. A simple computer program is developed to send out relevant text. Pagers used by Hamilton Sundstrand are capable of receiving text, which makes the implementation much easier. Integrating with external paging provider would make this approach impractical.

In order to make the hierarchical approach work, the Andon paging system needs a way to be notified by the paged parties who have actually responded to the event so that timers can be turned off to avoid escalation. It could be a web page through which timers can be manually turned off. In our vision, this should be an automated procedure, especially at the supervisor level. The only way supervisors can turn off the timer is by being physically present at the line so his or her RFID badge can be picked up by antenna.

Only then, the event timers could be turned off. While RFID badge is already in use at Hamilton, RFID badge readers are not available for our prototype.

5.4 Data Collection

Design and implement a comprehensive information collection system is the hardest part of digital factory. Some information will be readily available, such as how many times a line comes to a stop; how many time operators have to work overtime to meet daily requirement. Some information, on the other hand, is not so easy to collect, specifically test and quality data. Their collection processes are inherently manually intensive. Automation and complete computerization of these processes will be extremely difficult and unlikely be accomplished in the near future.

Our friends in Hamilton's IT department made some progress in this area. It's a partial solution that based on web applications. While the processes still remain manual, a web based interface deals with issues such as unreliable paper trial and poor handwriting, and provides benefits such as range check, data validation and error prevention mechanisms. This will remain most technologically challenging part of digital factory going forward.

Chapter 6: Overall Development Strategies

The following are key points in this chapter:

- A revisit of overall 787 project's strategic goals
- Identify key areas digital factory needs to focus in order to align with strategic goals
- An overview of company's resources
- Implementation recommendations to bridge the goals and available resources

It is important to recognize that digital factory should be designed to work with the entire value chain and it would require a sustained effort from Hamilton Sundstrand to make this work.

6.1 Mission Statement/Strategic Goal

Investment in information technologies for manufacturing firms often achieve mixed results [Montgomery, Levine, 1996]. It is important that we spend effort to ensure project would yield expected return. The very first step is to have a well defined goal or target that the project team should all understand and agree upon. Some people call it mission statement. The bottom line is that there should be a written statement that serves as the "constitution" that provides guidance to ensure a project's success. This is particular relevant in our case. The exact boundary of the project is not well defined. As we have mentioned before, digital factory is a cross-functional project that affects almost every aspect of Hamilton Sundstrand's business. With limited resources, we must focus our effort on things that would give "biggest bang for our buck". This is as much a project of integration as a project of prototyping and experimenting.

In order to come up with a clear forward looking statement, let us examine the umbrella project of which digital factory is a part. We will use the overall project's mission statement as the starting point. The Hamilton Sundstrand's Boeing 787 component assembly line team is to (*direct quote from the official team document*):

Develop an efficient, effective and safe continuously moving assembly line, digital factory infrastructure, integrated test equipment, material flow plan from vendor into the airplane, and manufacturing support processes. Embed automation, mistake proofing, lean practices, and QCPC to enable the Operations area to achieve ACE Gold on the onset. Manage the project to provide full up capabilities for systems evaluation by May 11th, 2006.

Digital factory is mentioned as a part of the project and of the overall mission statement, but no clear definitions nor guidelines are provided as what would constitute a digital factory and exactly how it would fit with the rest of assembly lines. As we begin carefully constructing our mission statement for digital factory, keep in mind of two things: 1) this statement is something that we will constantly come back for reference and

guidance 2) although we are using the above statement as a starting point, by no means is the mission of digital factory limited or confined by the overall project as long as it serves the overall project well.

The purpose of digital factory is to establish effective information flow and communication that are *necessary* for Hamilton Sundstrand to successfully fulfill Boeing 787 contracts. Information here can be just about anything, including ideas (exchanged between humans), data (travels between customers and Hamilton), and device controlling signals. The basic definition of success is on-time and on-budget delivery of 787 modules/components that are ready to be installed into aircraft. This also means that components will be shipped on time with guaranteed quality. With this in mind, we can proceed to pin down a concrete objective specific for digital factory:

Digital factory is to develop an *effective* information *network* that Hamilton and its business partners will *rely* on to achieve the following:

- 1) Keep the assembly lines moving at a just-in-time pace based on lean principles. To do so the digital factory needs to address three key areas:
 - a. Part shortage
 - b. Quality parts but don't fit together
 - c. Fail to pass tests
- 2) Track, circulate and archive essential quality and process data and make them available and searchable for Hamilton and its customers. Especially to provide multimedia capability to facilitate discussion
- 3) Collect and prepare comprehensive production data report for both short term and long term process improvement.

We believe that this statement is clear enough so that we understand goals that we need to accomplish and general enough so that we can apply it widely in our implementation. With the following annotations, this statement will be specific enough so that it will provide detailed guidance.

Effective – It is very difficult to define what level of achievement is considered effective. In addition to accomplishing the three explicitly stated objectives, specifically we want our information network to be inexpensive, extremely reliable and simple-to-adapt. These three criteria will help us decide in choosing between various technologies and implementation strategies.

- Cost – It is extremely difficult to estimate concrete financial benefits for the digital factory project because it is so far ahead of the rest of Boeing 787 project at Hamilton that no assembly lines are operational and everything is still in the

planning phase. There are no productions or experiments that we could set up to collect any performance data. The smaller the upfront capital investment, the less risk the company is exposed to and the easier management will approve. Furthermore, small capital requirement also translates into fewer political battles and organizational challenges.

- Reliability – system reliability is an absolute requirement in industrial setting and in business in general. Technologies are expected to keep the pace with production 24/7. Frequent Microsoft style crashes and glitches will quickly cause a promising technology to be dismissed prematurely.
- Adaptability – is another often overlooked area in term of introducing. An overly sophisticated user interface will not only make training very difficult, but more importantly will cause errors, mistakes, resentment and frustrations, which would people easy excuses not to use it. Simplicity (and familiarity) is our best strategy in dealing with complex development project.

Network – Our information network or digital factory is as much a traditional *hard* data network that consists of computers, routers, cables, scanners and databases as a *soft* network of human interactions and behaviors. We naturally associate terms like information systems with high power high bandwidth computing machines and optical links, but often time forget the most important part of a network, humans. In our discussion of development framework, we will address both hard and soft network implementation strategies. Both are required in order to have an information network that works.

Rely – This is a nice way of saying “usage of the information system is mandatory”. There should be at least as much effort to implement the information network/system as to incorporate such a system into the overall production system. This is not fundamentally different from instituting standards in operations such as QCPC to achieve higher productivities and quality. We set standard ways that communications should be managed to enjoy faster and more transparent information flow. This will be difficult and probably most challenging because we no longer deal exclusively with technologies, but start to venture into the realm of organizational issues.

Of course, these three qualities do not exist in isolation. They work in conjunction to make the digital factory project practical and useful.

6.2 From Mission Statement to the Specifics

We will now start from our mission statement to map out in-depth tangible requirements for the digital factory.

6.2.1 Keep the Line Moving

A moving assembly line dictates production pace, creates a sense of urgency for everyone working on the line and enhances visual management. Based on our conversation with operators, supervisors and manufacturing engineers, the following three problems will halt assembly lines

- Part shortage or parts with quality issues
- Assembly difficulties: typically with parts that meet specifications but very difficult to be put together
- Modules fail test

There are other factors that can also force an assembly line to stop. But we want our digital factory implementation strategy to directly address the most important needs in operations. These three are by far the most common factors

Part shortage (or parts with defects) - is a major disruption to current production at Hamilton and it is to a large extent not within Hamilton's control. The fact that Hamilton, its suppliers and Boeing are all moving towards pull-based just-in-time delivery system and are not willing to carry any unnecessary inventory will only manifest the part shortage problem. It is critical that Hamilton Sundstrand develop a robust supply chain to guarantee that all assembly lines are well supplied. And this is the exact reason we want to think about how our digital factory be designed to help the production system establish such supply chain.

Difficulties in putting parts together – is one of another common headaches that most operators have to deal with on a daily basis. Very often operators will run into parts that are fall within required specifications but it is just very time consuming trial-and-error process to put these parts together. For instance, connecting components with ducts is a typical assembly step that would have this problem. Operators will have to try (and have to manually cut) ducts with various length before they can finish the connection. Even if it doesn't stop the line, this adds a lot of variation into the process. This will be especially problematic during the ramp-up stage in which everyone will be still trying overcome the learning curve. Again, in designing our information system, we want to think about how we can address this problem.

Components fail tests – the build process will have different stages of testing. Some will be conducted inline and some offline. For instance, some of the connection testing is likely to be performed as part of built. Sometimes operators will try to perform simple debugging themselves, but most of time, supervisors and mechanical engineers will be involved. It is essential that the crew figure out why tests fail quickly to restart the line.

In summary, our digital factory implementation strategy should be carefully considered to focus our attention on these three issues.

6.2.2 Quality Data

Digital factory will need to improve Hamilton Sundstrand's technical capacity of converting quality data to useful information. Hamilton Sundstrand has a lot of historical test data had been recorded for a wide range of products. Many were done with paper and pencil. This essentially makes any sorts of analysis prohibitively slow and expensive. Without easily accessible quality data, it would make process improvement very difficult. We believe that being able to quickly establish rapid some quality data feedback will be particularly useful in the ramp-up phase.

We are building new assembly lines. This is an excellent opportunity for Hamilton Sundstrand to change paper-pencil practice and focus our development effort on

- Recording quality measurement data on a digital medium.

Note that the focus is "on a digital medium". It could still be a manual process to enter data into digital format if it makes operational sense. The important point here is that 787 component's quality data, especially portion that Boeing cares about, must be kept in digital format for easy access and statistical analysis.

6.2.3 Long Term Process Data for Performance Improvement

The third bullet in the digital factory mission statement is a longer term target than the first two. The new assembly lines will be operated based on lean principles. As a matter of fact, the entire company is going through a tremendous lean transformation. The essence of lean is constant improvement. We believe that the digital factory should also be designed to be in line with lean principles.

- To develop a simple but scalable process data management system (could be based on existing MRP system) should be one of the long term focuses of the digital factory

This database will store and manage detailed production information such as inventory level and direct labor cost. The information will facilitate long term process improvement. Hamilton Sundstrand should take this opportunity to upgrade and align its information system with its operations' goals. Digital factory provides a natural platform.

6.3 Resources

In order to design an effective implementation strategy, we need to understand the resources that are available to Hamilton. We will examine relevant resources that will be directly useful for digital factory development as well as peripheral resources that will have potential impact on our development effort.

Equipment/Tooling

As expected, Hamilton Sundstrand has no shortage of traditional heavy machineries and work cells. They are used for blade, segment gear, and other detail manufacturing. There are a few small assembly lines for air management systems, but they are not automatic moving lines. Work-in-progress is moved between work stations with manual cart to achieve the effort of moving line. There are some Andon stack-lights in the plant, but based on our observation, most of them do not function as their original intent. There is one track on the factory floor that can be readily used for the new assembly lines, but Hamilton will likely need quite a few more for the Boeing project. The Windsor Locks facility has a well run tooling shop that can customize or make devices or apparatus. This comes very handy for computer equipment installation for new assembly lines.

Human Capital

The work force at Windsor Locks can be described as highly experienced in detail manufacturing. Many people have been with Hamilton Sundstrand for over twenty years, including both hourly operators and salary support staffs.

Operators are grouped roughly based on product line. Cross training is also within the product line boundary. There is a wide range of mix in terms of level of sophistication and complexity involved in manual work. There are relatively straight forward tasks such as machine batch loading and operating. There are also plenty of highly sophisticated tasks that require extensive skills and experience in precision machining, rotor balancing and blade finishing. People take pride in the work that they do. Operators on the shop floor are generally comfortable with using computer for their daily routines, whether it's web browsing, document retrieving or data entry. They all have logins and company emails. Everyone knows about the principles of lean and has in one way or another prior exposure to the concept. However, very few actually embrace lean since they equate lean to job cutting.

Manufacturing and test engineers work closely with operators on the products they are responsible for. Their offices are located in the plant. They design and control the manufacturing processes, program machineries, resolve quality problems and maintain various production documents and work instructions. Most engineers have been working for the company well over 10 years and extremely knowledgeable about products and their processes. In addition, they have a very good sense about whether certain tasks (like adding a small crane) would be feasible the Windsor Locks facility. Their computer skills tend to be specialized to the machines they are in charge of. Some are proficient with more common programming skills such as Visual Basic, C++ etc. However, the overall level of computer skills can be categorized as "enough-for-the-job".

Design engineers are not co-located with manufacturing engineers and operators on the shop floor. They usually are not involved heavily with the manufacturing activities. Their primary responsibility is to design the product based on customer's requirement and work with manufacturing engineers to ensure the design is manufactureable.

Under Tony's organization, there are a solid group of people who handle finance, quality, material flow, process improvement, performance analysis and production planning. They are a smaller group compared to engineers and operators.

Communication/IT Infrastructure

The existing communication and IT infrastructure can be described as "typical". The shop floor and offices are connected by 100 Mbps standard network. As a part of digital factory project, Hamilton installed its first wireless zone, but it is not connected to the intranet. Based on user experience, the network seems to be rather slow at peak load. It is worth noting that Hamilton and all UTC companies actually do not buy any computer and network equipment. Everything is outsourced and contracted out to a third party vendor. All the computers are actually leased instead of owned. As a result of that, no one (maybe with exception of few) in the company, not even the IT department, will have administrative access on any of the computers. We are not allowed to install any software or change any hardware. The vendor can provide such service if the request has been authorized by corresponding managers. The process for such task is slow and can take up to a week.

At the heart of Hamilton's IT infrastructure is a large material and product planning system called JDE. This database system facilitates material flow, production scheduling, inventory control, performance analysis and cost accounting. Different functional groups are connected through this system. At this point, they are improving the user interface. The learning curve of JDE is steep and extracting data in a user friendly format is particularly challenging. The system has been in place since mid-nineties. Despite of some of its shortcomings, there are no compelling reasons for Hamilton Sundstrand to invest in a major upgrade or replacement.

Salary staffs are usually equipped with pager, email, desktop telephone and fax. I personally found paging services within the plant sometimes unreliable, but mostly caused by misuse by paged party rather than the actual system. Some have company paid cellular phones while most people use their own cellular phones. With exception of Sprint, who puts a signal booster on the roof of the plant, the reception for most other wireless networks are very weak and unstable. Director level personnel are given Blackberry or equivalent mobile email communicators.

Informal and unofficial document used on a daily basis by teams are managed through typical Microsoft Windows' shared network drives/folders. This system can occasionally become inadequate due to large file transfers or slow due to accumulation of obsolete files.

Work Atmosphere/Company Culture

Hamilton Sundstrand is actively pursuing manufacturing excellence and competitive edge in the global market. This translates into a work environment in which efficiency, on-time delivery and quality are highly valued and rewarded. However, due to a series of recent cost-cutting and outsourcing decisions, the work force experienced some morale setback. We believe that this is now behind Hamilton. Many veterans, especially among salary staffs, hold an optimistic outlook of future for the company as the 787 contract will help transform the Windsor Locks' plant from a detail manufacturing shop into a high value-added assembly power house.

In general, any direct capital investments will be closely scrutinized and debated. In order to get approval from the site Director, an investment will need to demonstrate tangible returns as offsetting benefit to the bottom line.

Just like any large organizations, Hamilton Sundstrand has its formal organizational structures as well as informal personal peer-to-peer invisible networks that are very useful and effective in dealing challenges in operations.

The Team

The 787 production team is a very representative cross section of the Director's organization. It's a group with considerable amount of experience and talent. Many are managers of groups. They are very focused and committed to building an efficient and robust moving line production system.

Suppliers/Track record

We do not have any information on suppliers during the project. Therefore we need to be very careful and conservative in making assumptions about suppliers' ability to support future supply chain.

6.4 Implementation Strategies

We have analyzed objectives that are important to the success of the new 787 production and relevant resources at Hamilton Sundstrand. We will need a practical implementation strategy that would leverage existing infrastructure and experience to achieve these goals. Reviewing the five issues we need to address:

- Part shortage
- Assembly difficulties
- Failed test
- Quality data on a digital medium
- Long term process data for performance improvement

Some strategies recommended in the following section will not be considered as technical solutions as the name of the project would suggest. Instead, we will want to better understanding the role of digital factory in the overall framework.

Part shortage

Part shortages are not an easy issue because Hamilton is only a part of the overall supply chain and does not have full control. This problem is particularly painful when the buyer does not command the kind of market power that Dell has or if the supply network is long and complex. Once part shortage happens, it usually will be a lengthy phone-email-tagging process to work with suppliers in order to receive parts.

The most effective medicine for part shortage is forecast and prevention. This requires extensive visibility and transparency to be built in the supply chain. UPS/FedEx's online shipment tracking system provides a good example of what visibility means to end customers. Checkpoints are installed and integrated with central database. Packages travel through the delivery network and are scanned and registered along the way either by automated devices or human operators. The main advantage of technology-based approach is that once put in place and adopted, it will perform very consistently. More importantly, a good and reliable technology is much more likely to be instituted as an integral part of standard process in the supply chain. The disadvantage with technology enabled transparency is that we will not ever be able to put such technology in place simply because of its complexity, cost and organizational issues (such as who pays for what and suppliers' willingness).

Transparency and visibility can also be achieved without cutting edge technologies. For instance, Boeing and Hamilton can have dedicated personnel or delegates to work extensively with their suppliers to gain insights on suppliers' production process, disruptive issues and scheduling. This will allow Hamilton to better predict part shortage. The advantage of this approach is that it's much easier to get things started and it is much closer to how business is conducted traditionally. The major disadvantage is that this approach depends heavily on human involvement, which tends to be less consistent and sustainable. If Hamilton has a large supply network, then it has a scale problem, too. Finding right people for this kind of work can be challenging as well considering current tight human capital at Hamilton. Plus, this approach is susceptible to the same problem as technology-based approach, i.e. Hamilton might not be able to convince vendors to comply.

The implementation strategies of digital factory for part shortages are the followings:

1. Digital factory will be a part of long term supply chain integration and improvement. It is unrealistic to expect to build such as a system across heterogeneous business environment in a short time period.

2. First cut – identify critical parts/modules that have a high carrying cost and high stock-out cost. We want to rule out parts that have high stock-out cost but low carrying cost. It will be more practical to just have those in inventory than to develop sophisticated monitoring system over supply chain.
3. Begin the implementation with thorough analysis of the overall supply chain with following objectives. The goal is identify the weakest link that Hamilton can work with.
 - Categorize suppliers based on their past track records or industry reputations
 - Understand which suppliers are more likely to comply with Hamilton’s current requirements as well as future digital factory requirements.
 - Repeat the same analysis for tier 2 and tier 3 suppliers, even tier 4 if necessary
4. Continue to develop in house material flow and inventory monitoring capability demonstrated by our digital factory prototype. Based on the existing resource situation, external IT contractors or consultants will be needed.
5. Once Step 3 is completed and digital factory becomes an integral part of the production system, Hamilton can then push this technical requirement onto the suppliers identified in Step 2.
6. Develop a clear understanding of limits of the digital factory. The configuration of Hamilton supply chain can be very complex. Even with the forecast and prediction capability provided by the digital factory, by itself is not enough to solve the part shortage problems. Other mechanisms such as preventive contractual design with suppliers, higher levels of inventories and operational hedging (additional capacity) will be required to handle part shortages.
7. Develop contingency plans before hand in case the digital factory flags a potential “show stopper”. This will likely result in having contingency contracts with suppliers.

In summary, our digital factory can increase supply chain visibility, which would better position Hamilton to deal with part shortage. Digital factory will take a long term role in supply chain management. Other mechanisms such operational hedging will be necessary.

Troubles on the Assembly Lines

We will group previously discussed assembly difficulties and failed tests into one category because they have very similar requirements from digital factory. Let’s think about in a scenario in which an assembly line is stopped either because operators are having a lot of trouble putting parts together or because a particular test, either inline or off-line, has failed. What could digital factory provide in a fire fighting situation like this?

Presumably digital factory could contribute significantly in the design stage by providing next generation networked 3D design software that would minimize chances of duct connection problems happening. But the scope of the problem is usually confined within the operations, which a sharp contrast to that of the part shortages.

Anyone who has worked in a traditional manufacturing house would know that it may be difficult to locate people when you need them. Most plants are big, big enough that sometimes it is a waste of time walking around looking for people. In Hamilton, most people have pagers and their own personal cellular phones. But receptions in those big metal framed plants are usually poor. Our experience shows that quite often cell phones are unanswered and pages are not returned (a lot of times because the person chooses not to respond). Email is not suitable for immediate contact because most workers do not have devices like Blackberrys. In addition, people are often in meetings. With all these factors, it would probably take a good hour sometimes to bring everyone together to respond a situation. This means that assembly lines will stop for an hour longer that it should have. This is where our digital factory can contribute.

Our digital factory solution includes two parts.

1. Equipment upgrade: give the production team, including operators and maybe design engineers as well, Nextel (or equivalent) push-to-talk phones that are supported by signal boosters installed across the plant. This will allow people almost instantly contact each other with a proven technology.
2. Second part is a little more difficult and is the “soft” part of our digital factory. We need to establish a standard communication protocol in case push-to-talk fails to reach intended party. This is important because average work load at Hamilton is considered high. Without enforced priority, no technology is going to improve the communication. For instance, a simple rule could be that everyone should check their phone/page every 30 minutes so that no assembly stoppage related emails or voice mails will go unchecked for too long. It could also be that all meetings that involve key production personnel must post meeting locations and times in a visible well known location (maybe Andon boards?). The key here is to keep the protocol simple but enough so that there is constant communication among the team.

It is important to discuss the human aspect of improvement in team communication. This is as much about upgrading equipment and putting right protocols in place as changing people’s mentality and behavior. They can be quickly gathered to resolve an assembly difficulty if they want to, even without help of modern telecommunication equipment. People will find an effective way if they are motivated. We need to develop that kind of mentality of on-call medical doctors or client serving lawyers who would go out their way to ensure that they are always in the loop. While exactly how that’s done in a large organization is out of the scope of this thesis, it is something that we should keep in mind.

Quality Data Management

Hamilton Sundstrand can definitely benefit from better quality data management. Challenges will come from two fronts, data collection procedures, and data storage and management. In data collection, there are both paper-pencil entry and computer based entry. In storage, data is kept in both various Excel sheets and JDE, the central database. The recommended implementation steps are the followings:

1. There should be no paper-pencil recorded data by operators. Everything must be recorded on a digital medium. Once new data sheet format and content are finalized, it should be converted to either an Excel sheet with entry fields or web based application that allows operators to enter data. Hamilton's IT department is already working on web based prototypes.
2. Regardless what interface we choose, Excel or HTML pages, each data entry field must have very strict value range verification checks. Granted that this will not completely prevent operators from making mistakes in entering data, it nevertheless provided first line of defense against human errors.
3. Hamilton's management of quality data that's already on digital medium is fragmented. Due to organizational and other legacy restrictions, the current way of data management will probably not be changed significantly in the immediate future. JDE is very powerful but not user friendly. Data retrieval can be difficult. It would make sense to keep copy of complete quality data in Excel files to be shared among the production team. At Windsor Locks facility, they already have a small team that quickly generates user friendly data from underlying JDE data repository.

In summary, we want to remove paper and pencil from the data entry procedure. There can be a mix of direct entry to both JDE and Excel files. However, we should have a final unified all encompassing Excel file collection that contains all quality data for easy access. These objectives are very reachable and well within existing operations capacity, but will be a nice incremental improvement in terms of digital factory development.

Long Term Performance/Process Improvement

Long term process improvement predicates on good quality data management. It will be a long term plan, similar to the solution strategy for part shortage. The focus of short term implementation is to identify set of performance metrics that cannot be measured without digital factory. Followings are the key steps:

1. Start to construct an appropriate performance metrics that can help us identify what's important to measure. This can be a difficult step. For instance, we might want to measure how long expensive component stay in the assembly area, but not on the line, or we might wish to understand during which build stage an

operator will have most trouble fitting parts together. Maybe with proper positioning of RFID, we can even accurately measure distance an operator has to travel per shipped module. So, potential data volume and variety can be very large.

2. Start small with Microsoft Access Database. It is better equipped than Excel to handle large amount of data and Access is small and simple enough so that average engineers with some software programming knowledge can still build a very powerful database application. In our prototype, we used Access to store RFID location updates and other information.
3. Database management requirement will be more sophisticated and demanding. Access will eventually not be adequate simply because of the amount of data. While during the experimentation period it is possible that Hamilton can develop everything in house, at some point, Hamilton will need to hire dedicated personnel or external consultants.

In summary, for long term performance improvement, contribution by digital factory will largely depend on its ability to measure detail production parameters that was not possible to measure before. The focus of the implementation is to understand parameters that would yield more insights about productivity and use simple database technology to get things started.

Chapter 7: Conclusion

The digital factory project has three achievements:

- 1) Developed a proof-of-concept prototype that demonstrates capabilities of a real time information system. With simple RFID equipment and off-the-shelf Microsoft office tools, we are able to put together a fairly sophisticated work-in-progress tracking system. Additional capabilities include automated work instruction display and Andon response.
- 2) An opportunity for Hamilton Sundstrand to have an extensive assessment on future learning curve for developing modern assembly lines and technological infrastructures. The project demystified RFID and explores ways that this new technology can fit into existing operations.
- 3) A good exercise in terms of structuring implementation strategy of a project that lacks well defined boundaries yet has far reaching impact. Digital factory will need to establish a combination of both long term and short term goals based on operations and customer needs. The most effective strategy does not necessarily include most cutting edge technologies. Other factors such organizational infrastructure, market power within the supply chain and human behaviors can play significant roles.

There are a number of other important issues in digital factory implementation, which are not discussed or addressed in our project.

- Robustness – this is one of the most important attributes that digital infrastructure in a factory should have. How to build a reliable computing system that would not only provide critical service but also not cripple production with system crashes.
- Flexibility and scalability – assembly lines change and improve over time. Customer requirements and supply network evolve, too. Design of technological infrastructure will need to be flexible enough to accommodate future unknowns.
- Performance metrics – it is easy to explain what obvious benefits that digital factory could bring, but it is not easy to quantify such benefits in financial terms that can be communicated to management. Having the right performance metrics is important for getting people's buy-in.
- RFID – it is easier to build a RFID prototype in a closed setting, but it will be difficult to implement RFID across different business environments. Understanding technology trends and industry standards will be crucial.

- Integration with legacy systems – rarely do we have an opportunity to work with a green facility. Backward compatibility will determine success of the project. In Hamilton Sundstrand, fitting everything with JDE will be a major undertaking.
- Data modeling – for an integrated information system for the entire value chain, it is always challenging to find a comprehensive and flexible data modeling scheme suitable for all stakeholders [Sheer, 1995].
- The role of system integrator – cooperation is essential in a project like this due to the scope of the project. In addition, the system integrator must be able to work closely with multiple suppliers [Gerelle, 1988]. It is important that we understand what kind organizational support a system integrator should have. This can be an interesting organizational processes study.

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