# ARCHITECTURE DESIGN OF A COLLABORATIVE DECISION SUPPORT SYSTEM

by

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Submitted to the Sloan School of Management and
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in partial fulfillment of the requirements for the degrees of

**Master of Science in Management**
and
**Master of Science in Electrical Engineering and Computer Science**



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## ABSTRACT

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Dell Computer Corporation, renowned for its "direct model" and build-to-order strategy, has identified virtual integration – i.e. real-time collaboration between all the internal steps of its order fulfillment process, as well as seamless sharing of information between the company, its suppliers and its customers – as a means to continue its growth in future.

This thesis focuses on a newly commissioned factory, designed as a first step towards virtual integration, to manufacture Dell's high volume corporate desktop line of computers. This factory combines business processes that were previously performed in separate locations. The factory uses a hybrid of localized and centralized decision-making to manage its operations, which proves sub optimal in coordinating decisions throughout the high velocity order fulfillment process.

This thesis proposes an alternate approach to managing such an integrated factory via a centralized operations control center, which allows for collaborative decision-making between all the elements of the supply chain. The thesis benchmarks other manufacturing and service industries to understand best practices. The thesis then develops the architecture for Dell's operations center that specifies the business processes managed in the centralized operations center, the facilities aspects that support these business processes, as well as the information technology architecture that enables coordinated decisions. Further, this thesis analyzes and quantifies the financial impact of the proposed solution. It also examines the pertinent organizational aspects at Dell that enables and hinders the corporate vision of virtual integration in the context of the new factory.

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## 1.1 INTRODUCTION

The work presented in this thesis was completed as part of a six and half-month internship at Dell Computer Corporation's World Wide Operations group in Austin, TX. This internship is a result of a partnership between Dell Computer Corporation and the Leaders for Manufacturing program at the Massachusetts Institute of Technology. The project was in a new factory that manufactures Dell's Optiplex line of computers.

Dell Computer Corporation is renowned in the industry for its Direct Model approach to customer order fulfillment. This mass customization manufacturing method implies that every computer system is built against a specific customer order. Dell also offers its customers the latest product features built using standard technologies and components. Customers like the convenience of buying systems built for them based on their specifications. As a result, Dell has experienced 50% year over year increase in demand for the past several years. Dell has responded to this rapid demand growth by building new factories every two to three years.

In May 2000, Dell commissioned a new factory in Austin to builds its corporate desktop line of computers called Optiplex. The Optiplex factory was designed to integrate all the steps in the value chain from order scheduling and computer assembly through distribution and shipping. As this new factory consolidates several operations in the same physical area as of an older factory, the productivity and sophistication increase significantly. These conditions dictate a more complex manufacturing environment, where many decisions have to be made quickly in a collaborative manner across various functional areas. The older factories are managed by line of sight, locally on the plant floor. However, the need for integrated decision-making and execution make it inefficient to manage the new factory using the traditional line of sight management.

This thesis explores an approach to managing this complex factory via a centralized operations center. The primary goals of this project are:

1. Identify the opportunities for a centralized operations center to streamline the management of Dell's newest factory building its corporate desktop line of computers.

2. Design the architecture of an operations center that encompasses

    1. Business processes,

    2. Facilities, and

    3. Information technology architecture aspects.

## 1.2 THESIS OVERVIEW

Chapter 2 presents background information on Dell in general and its operations in particular. The chapter describes the evolution of Dell factories, and the business processes involved in managing the factories. It discusses Dell's future strategy of virtual integration to continue its growth. It presents a case study of Dell's newest manufacturing facility, designed as a first step towards virtual integration. The chapter then illustrates how the traditional approaches to managing the factories do not scale to this new facility. It proposes an alternate approach to managing this factory through a centralized operations center. Thus, this chapter presents the opportunity identification or the strategy phase of the project.

Chapter 3 presents the benchmarking of leading industries in manufacturing and in service sectors. The benchmarking effort is divided into three functional areas: business processes, facilities and information technology. The chapter briefly describes the salient features of each benchmarking visit along the three focal areas, and the lessons learned from them.

Chapter 4 presents the architecture design of a collaborative decision support system for Dell's Optiplex factory along the same three aspects: business processes, facilities and information technology.

Chapter 5 describes the financial impact of the new management system.

Chapter 6 illustrates the implementation aspects of the project. It also describes some of the organizational issues that facilitates and hinders the project.

Chapter 7 presents the conclusions drawn from this project.

# 2 BACKGROUND AND PROJECT DEFINITION

## 2.1 CHAPTER OVERVIEW

This chapter begins with a brief overview of Dell Computer Corporation's business model and its supply chain processes. It then presents the corporation's future growth strategy via virtual integration. A newly designed factory for building Dell's corporate desktop line of computers is a first step towards achieving this virtual integration. This chapter examines the management system at this new factory, illustrates the problems in the management system and identifies opportunities for improving this system. Thus, it presents the context and motivation for the project.

## 2.2 COMPANY BACKGROUND AND POSITION

In the early eighties, several computer manufacturers and assemblers licensed IBM PC architecture and Microsoft's DOS operating system, and started making personal computers [1]. Dell Computer Corporation was founded by Michael Dell, who began assembling computers in his dormitory room in the University of Texas, Austin in 1984. As demand for assembled computers grew, Dell dropped out of college in his freshman year, moved to Round Rock, Texas, and established the headquarters of Dell Computer Corporation [2].

Since then, the company has been growing steadily. It expanded to add international sales offices in 1987 and in 1988 the company started selling to government agencies and added a sales force to serve larger customers. That year Dell went public. The company began its short stint in the retail market in 1990 by letting Soft Warehouse Superstores (now CompUSA) and office supply chain Staples sell its PCs at mail-order prices. Also in 1991, Dell opened a plant in Limerick, Ireland. In 1992, Xerox agreed to sell Dell machines in Latin America. Dell opened subsidiaries in Japan and Austria in 1993 [2].

In 1993 after making losses, Dell decided to pull out of the retail channels. In 1994 the company exited its retail store strategy to focus on its mail-order origins to sell directly to customers. This allowed the company to save the margin it paid to resellers. With the widespread adoption of the World Wide Web in 1995, Dell moved to taking orders online. This fueled the accelerated growth that Dell has experienced in the mid to late nineties [2].

In 1996, Dell ramped up operations in the Pacific Rim. It also started making workstations and built up its consumer business by separating that operation from its small-business unit and launching a leasing program for individuals. In 1998, it also entered the market for servers and storage products. Also in 1998, Dell announced the expansion to Nashville, TN to build its consumer line of computers (Dimension desktops and Inspiron notebooks). Continuing its global expansion, Dell opened a plant in China in 1998 and made plans for a manufacturing and customer center in Brazil (opened in 1999). Also in 1999, Dell made its first acquisition by buying ConvergeNet Technologies, a California-based maker of storage area network equipment, in a $340 million deal [2].

The premise behind the company's strategy is simple and straightforward – by selling computer systems directly to the customer, Dell can best understand their needs, and efficiently provide the most effective computing solutions to meet those needs.

Today, Dell is a major computer systems company, with a revenue run rate of $32 billion and more than 40,000 employees around the globe. Dell's worldwide market share has grown over the years to number two by the end of 2000. The company ranks number one in the United States, where it is the leading supplier of PCs to business customers, government agencies, educational institutions, and consumers [3].

60% compound aggregate growth (CAGR) in demand that Dell faced over the years has necessitated that the company build new factories every two to three years. Early Dell factories built multiple types of computers. Each line inside a factory was dedicated to a type of computer. However, with the proliferation of product lines, the company now dedicates each factory to building a separate line of computer in the US.

Dell obtains a significant amount of its revenues from the corporate market. The corporate desktop line of computers, Optiplex, comprises roughly 40% of the volume of computers that Dell makes every year. Customers include private sector firms (large, medium and small enterprises), public sector (federal, state and local governments), and educational segments (K-12, colleges and universities) [4].

## 2.3 DELL'S COMPETETIVE ADVANTAGE

Dell's competitive advantage stems from its build-to-order model for order fulfillment. Dell pioneered this method of demand fulfillment in the computer industry. This demand-driven model, also referred to as the Direct Model, allows the company to make computers against a firm order. The flip side of the build-to-order approach is that the company faces tremendous variability in the order profiles in real-time. Dell responds to this variability by keeping low amounts of inventory in hand, and uses supplier warehouses close to its factories. These warehouses can supply components necessary to build computers several times through out the day [5].

The ability to be responsive to customers, to operate with low levels of inventory, and to adapt to rapid technological change are the keys to being competitive in the computer hardware industry today [5]. Dell's build-to-order model eliminates the need to add value-added-reseller (VAR) operations and incentives. This helps the company to offer better prices and own the relationship with its customers. In addition, the build-to-order method reduces the cost and risks associated with keeping large inventories of components and finished goods from obsolescence. Carrying low amounts of inventory has enabled the company to offer new products as soon as they become available and thus improve its competitive position within the computer industry. Further, Dell does not start building a computer until it has been paid for. Dell receives payments for its computers before it has to pay its suppliers. This affords the company a negative cash conversion cycle [5].

Thus, Dell's build-to-order model has allowed the company to excel against its competitors in the following areas [6]:

*Price for Performance* – With their efficient manufacturing and distribution process, Dell offers its customers powerful products at competitive prices as soon as they become available.

*Customization* – Every Dell computer is built to order to fulfill customer needs and requirements.

*Latest Technology* – Because of streamlined operations, Dell is able to introduce the latest technology more rapidly than its competitors. Inventory is kept to a minimum, reducing the holding costs and the chance of obsolescence.

*Service and Support* – Dell uses direct contact with the customer to improve operations and the overall customer experience.

*Shareholder Value* – Since Dell's initial public offering in 1988, its stock has appreciated more than 250 times.

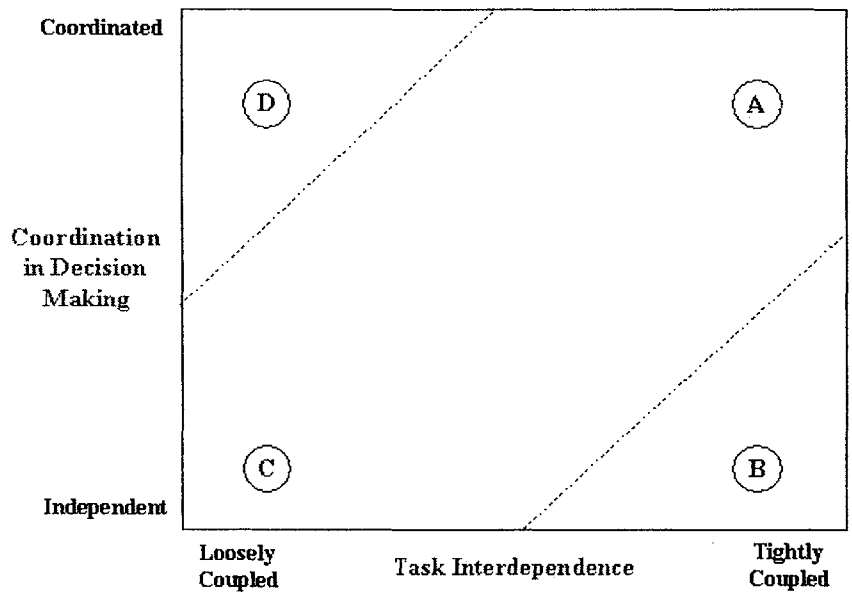
## 2.4 FUTURE STRATEGY – VIRTUAL INTEGRATION

Dell Computer Corporation's future strategy aims at positioning itself as an internet infrastructure systems company, providing products and services to all sectors supporting the growth of the internet. In the increasingly competitive computer industry, the company plans to improve its market share and its profitability by increasing the efficiency of its operations through "virtual integration" – integration of information flow in real time between the various functions of the value chain internally, and between the company, its suppliers and its customers externally. This strategy articulates that successful virtual integration will allow Dell to streamline its internal operations and serve its customers more efficiently in future by knowing and incorporating their needs in its products and services [7].

As Dell has grown to become a global company, it has had to increasingly contend with geographic, cultural, organizational and other functional boundaries. Given that, one of the key aspects that will make the virtual integration a success is an organizational culture that encourages greater collaboration and coordination of business processes across these boundaries. Another aspect that is key to the effectiveness of the strategy is an information technology (IT) architecture that facilitates seamless data, information and knowledge sharing throughout the company.

To summarize, success of the above strategy demands a closely integrated operation internal to Dell that coordinates data and information flow between various parts of the value chain. According to Janice Klein, such operations that are tightly integrated (a lean system) work well when decision-making is coordinated across all the areas involved [8]. Figure 1, adapted from her research, examines the relationship between task interdependence and coordination in decision-making.

**Figure 1: Coordination in Decision Making vs. Task Interdependence**




Tightly coupled operations, represented by corner A, are optimally managed through great coordination. Loosely coordinated operations, represented by corner C are best managed independently. Corner D, where loosely coupled operations are managed via coordinated decisions, results in inefficient use of resources. This is because there is no need for such coordination in this set of operations. Corner B is also not an efficient way of managing tightly coupled operations. Here, the tight interactions between the process steps necessitate coordinated decision-making; so independent management of such processes often leads to sub-optimal decisions.

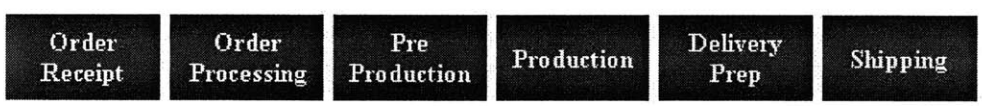
Thus in order to effectively implement its vision of virtual integration, Dell Computer Corporation has to not only integrate its business processes and IT systems across its value chain, but also coordinate decision making between the stakeholders in its integrated processes.

In light of this, this section presents an overview of the business processes, IT systems and organizational culture at Dell as a preliminary step in assessing the organizational readiness towards virtual integration. The processes examined below comprise the core of Dell's business, namely order fulfillment.

### 2.4.1 ORDER FULFILLMENT PROCESS AT DELL

The steps involved in Dell's order fulfillment process are shown in Figure 2. It begins when a customer places an order online or via telephone or fax. Typically, customer payment is also received along with the order. The second step, order processing, involves order verification and financial approvals. The order is then sent to pre-production, where it is scheduled for production. This scheduling process ensures that all the necessary components are available internally or at the supplier warehouses. It also assigns a specific line in a specific factory in which the computers belonging to that order will be built as per the customers' specifications. Components are then brought in to the factory. Each computer is assembled against the customer order. The hardware components are tested; software is uploaded and tested again. The computers are then packaged in boxes along with the peripherals that the customers ordered. The computers and peripherals are accumulated into specific customer orders in the delivery prep area, and are then shipped to the customers so that they receive the computers on the day they had specified earlier.

**Figure 2: Dell's Order Fulfillment Process**




### 2.4.2 INFORMATION TECHNOLOGY (IT) ARCHITECTURE

Information technology systems support the core processes of receiving orders via the company's website, order processing, order scheduling, manufacturing, distribution and shipping. Many of these software packages have been built over the years, and have different capabilities. They have different architectures, as they have evolved over time.

### 2.4.3 ORGANIZATIONAL ASPECTS

Based on the value chain in Figure 2, the stakeholders in the order fulfillment process are the customers, product-marketing personnel, order-processing personnel, manufacturing personnel, and distribution center personnel. These stakeholders typically have different backgrounds, expectations, and perspectives. Many Dell employees, who come from different organizations, bring their prior experiences and organizational culture with them. The interests of these different stakeholders must be aligned to create a sharing culture.

## 2.5 NEW OPTIPLEX FACTORY – A CASE STUDY FOR VIRTUAL INTEGRATION

Dell's newest factory has been devised to build the high volume Optiplex line of computers. This factory with its pioneering design enables a new model for efficient order fulfillment – a first step towards virtual integration.

Dell treats its factories as cost centers. Naturally, the main objective of the factories is to fulfill their customer demand, while making profits [9]. Factories meet their profit objectives by managing their costs. One of the major components that contribute to factories' costs is productivity. Improving productivity in Optiplex manufacturing will have a big impact on corporate profitability due to the high volumes of this product. Given this background, the World Wide Operations group at Dell has designed the new Optiplex factory to achieve significantly higher productivity than existing Dell factories.

Traditional Dell factories only handle order scheduling and manufacturing functions. Usually, the distribution (also called delivery preparation) and shipping functions are performed in dedicated distribution centers. However, the new Optiplex factory integrates both distribution and shipping functions inside the factory. A novel automated storage and retrieval system has been custom designed to be the distribution center at the Optiplex factory. Thus, unlike other Dell factories, the Optiplex factory houses all the steps in order fulfillment from Pre-Production through Shipping as represented in Figure 2. Given that all Dell factories have the same area (x sq. ft.), the new Optiplex factory has higher design productivity [10].

Figure 3 provides a more detailed description of the order fulfillment process at the new Optiplex factory.

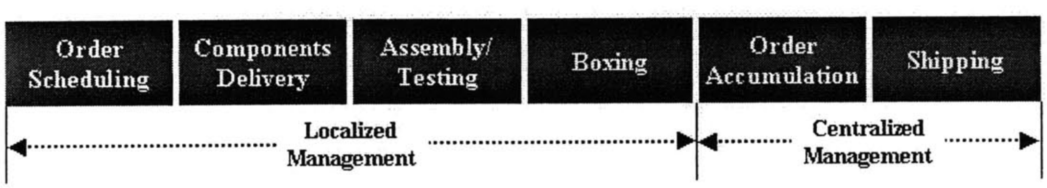
**Figure 3: Functions in the New Optiplex Factory**


The new Optiplex factory is innovative in other ways as well. For the first time in Dell's history, the factory's design uses three-dimensional space to increase throughput and productivity. As a result, this Optiplex factory has much higher design throughput than any other Dell factory. Also, this factory does not have any material storage locations inside it. Thus it is designed for very low inventory levels through out the factory [11].

## 2.6 MANAGEMENT OF THE NEW OPTIPLEX FACTORY

The Optiplex line of business manages the factory. As the factory was initially opened, Optiplex team used a mix of conventional and novel methods to manage the entire factory. The front end of the factory that schedules orders, brings in components in the right quantities from the supplier warehouses, assembles the computers and boxes them are managed similar to other Dell factories using localized line-of-sight management. The distribution and shipping areas, now integrated with the factory, use several new automated pieces of equipment. These sections are managed via a centralized control room located inside the new Optiplex factory. Thus the new factory is managed using a hybrid of localized and centralized approaches, as indicated in Figure 4.

**Figure 4: Hybrid Management Model at the New Optiplex Factory**



The control room is a new concept at a Dell factory. Its personnel monitor and manage the computer systems and customer orders in the distribution and shipping areas of the factory using a new piece of software that is custom developed by Dell's internal information technology (IT) group.

The following sections provide a description of the features and challenges regarding the business processes, information technology systems and organizational culture as seen at the new Optiplex factory.

### 2.6.1 ORDER FULFILLMENT PROCESSES AND CHALLENGES

> *"Process" is an organizing concept that pulls together absolutely everything necessary to deliver some important component of strategic value [12].*

Dell's manufacturing process is discrete, which is characterized by variability of individual components. As mentioned earlier, Optiplex management uses two different approaches to manage the factory. Challenges arise from the incompatibility between the two different management systems and from the metrics used to track different performance characteristics across the factory. In order to smoothly manage the factory and achieve virtual integration, different areas of the factory have to work together closely.

#### *2.6.1.1 Business Performance Metrics*

Optiplex factory uses different metrics in different areas to capture the same underlying entity. This arises from the different history of the individual functions accommodated in the factory. For instance, the front end of the factory often measures in terms of number of computer systems, where as the back end of the factory often uses customer orders as the basis. This difference between system-level and order-level parameters often makes it difficult to prioritize decisions across the entire factory, and leads to different areas inside the factory optimizing different things. Streamlining the operations in the factory requires that every part of the factory has to use the same units and metrics to track similar information.

Obtaining the metrics on or near a real time basis is also problematic. Often these metrics are captured using different pieces of software. For example, the production control group obtains these metrics using scripts running on a legacy system. The distribution area obtains these metrics from sensors attached to the control system that monitors box movements.

Due to the different IT systems involved in capturing metrics, data are often not consistent in real time.

Problems also arise from the lack of timely data-feedback to the appropriate areas of the factory. Quality metrics, captured at various parts of the plant, illustrate this problem. Currently, these metrics are not fed back to the areas that may have caused the problems, in a timely manner. For instance, an operator assembling computers cannot immediately learn about a defect arising from the way he (she) assembled the computers due to delays in feedback loops to computer assembly areas from the computer test areas. Further, these delayed loops mostly focus on problems arising from assembly quality and not so much on incoming components' quality. Thus it takes longer for a problem arising from a defective component to be prioritized and communicated to the supplier warehouses, so that they can stop sending additional defective components to the factory. Furthermore, the quality metrics captured from different parts of the process on incoming components, assembly operations and customer experience are often not tied together.

Thus the business performance metrics pose the following challenges:

1. Metrics used throughout the factory are not consistent;
2. Methods used to capture the metrics in real time are not consistent across different areas of the factory; and
3. Feedback of quality metrics to the pertinent areas of the factory is often delayed.

#### *2.6.1.2 Traditional Line-of-Sight Management*

As mentioned earlier, Optiplex management uses localized line-of-sight approach to manage order scheduling and assembly areas of the factory. The new factory, with its higher projected throughput and productivity, has been designed with a view to minimize inventory storage between the functions. This increases the interdependence between different tasks in the new Optiplex factory. Due to this interdependence, decisions in the factory have to be taken quickly so as to reduce the impact of any problems on processes both upstream and downstream. This demands greater collaboration across different areas, which cannot be fully achieved by local supervisors in the factory floor.

Due to integration of distribution and shipping functions inside the factory, the assembly areas need to communicate better with the distribution areas to ensure consistency of decisions throughout the factory. With the assembly areas using localized management, it becomes difficult to prioritize decisions uniformly across the various assembly functions.

Thus, the localized management of the assembly areas poses the following challenges:

1. Decisions in the computer assembly areas cannot be coordinated and prioritized easily; and
2. It is harder to achieve globally optimum decisions due to distributed decision makers in the computer assembly areas.

#### *2.6.1.3 Centralized Management from Control Center*

In the Optiplex factory, a centralized control room is used to manage the distribution and shipping areas. While designing this centralized management process, Dell could not leverage preexisting control room architectures (processes, control hardware and software) available off the shelf, as they are mostly designed for managing continuous processes. Hence, Dell designed its Optiplex control room in-house. Due to time and resource constraints, the current control room design is sub-optimal. Further, it focuses only on a part of the order fulfillment process of the factory. In the first version of software used to manage the backend of order fulfillment processes, control room operators have to wade through various screens to obtain relevant information. The operators make all decisions regarding system movements in the distribution and shipping areas, and then communicate the decisions to the personnel on the shop floor. The shop floor operators act as agents who execute these decisions.

This centralized management of distribution and shipping areas poses the following challenges:

1. Most if not all the tactical decisions are made centrally, while shop floor operators make almost no decisions. This reduces the shop floor personnel's effectiveness in contributing towards the factory's daily business goals;

2. Decisions that are centralized and localized are not well thought out; and
3. Most, if not all, instructions and information flow from the control room to the shop floor operators. When issues arise, this unidirectional communication flow delays problem solving.

Due to the new design of the factory with minimal work-in-process inventory, any issues in one part of a line, if not solved immediately, can hold up not only that line, but also the entire factory in a short time frame. Hence, these problems need to be resolved taking into account all the affected areas so as to achieve global optimization. The two different styles of management – localized and centralized – together with inconsistent metrics across the supply chain prevent seamless information flow and coordinated decision support throughout the factory.

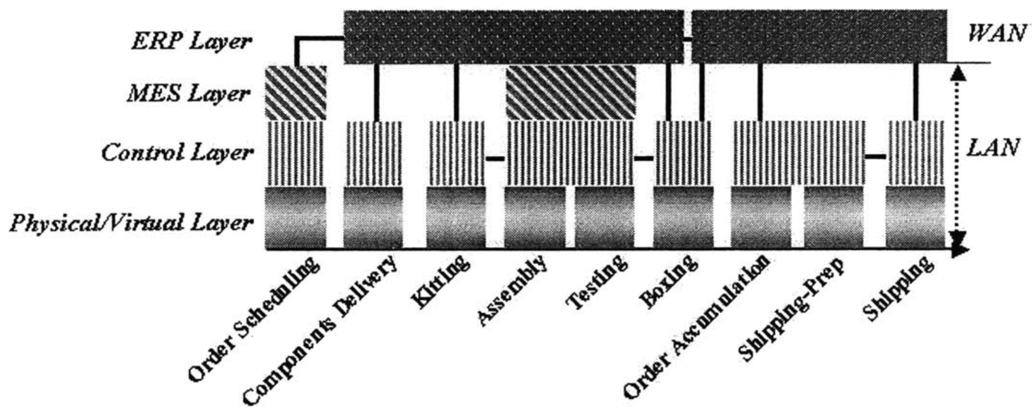
### 2.6.2 INFORMATION TECHNOLOGY (IT) ARCHITECTURE AND CHALLENGES

Despite the integration of manufacturing and distribution functions in the same physical building, communication between these areas of the factory is not very effective. This is due to the existing IT architecture used in Dell's order fulfillment.

Figure 5 illustrates the IT architecture used in the Optiplex factory. The figure uses the classification defined by the Manufacturing Execution Systems Association (MESA) in categorizing the various software systems and hardware controls in the Optiplex factory [12]. The physical/virtual layer is the first layer of the architecture defined by MESA. This layer involves all the conveyors that physically move computers as well as the software interface that tests the computers after they are built.

The second layer, called the Control layer involves PC based controls of the valves and conveyors. This layer is responsible for ensuring and monitoring the computer movements throughout the factory. As indicated in the figure, the control layer at the Optiplex factory does not communicate horizontally between the various process modules; instead it sends data and receives instructions to and from the layers above.

**Figure 5: Existing Information Technology Architecture**




The Manufacturing Execution System (MES) layer is the third layer. This layer can have 11 functions as envisioned by MESA. These functions are resource allocation and status, operations/detail scheduling, dispatching production units, document control, data collection/acquisition, labor management, quality management, process management, maintenance management, product tracking and genealogy, and performance analysis [12].

The first three layers typically reside in the local area network (LAN), and communicate with one another on a very frequent basis (almost in real-time). The fourth layer, called the Enterprise Resource Planning (ERP) layer, typically resides in the wide area network (WAN) spanning multiple Dell factories. It is often slower than the other three layers. Many of these systems in the ERP layer have been in use at Dell for a number of years.

The IT system used in Dell's computer assembly operations is an ERP system that runs on legacy mainframe computers and resides in a centralized location. The software, written many years ago, was designed to handle low levels of throughput. The software also controls multiple factories. These factories, which produce distinct lines of computers, differ widely in their throughput, product features and complexity. The loads they place on the legacy software vary throughout the day.

This legacy software performs all the functions that can be handled by the MES layer. It controls computer movements from one location to another inside the factories. It tracks information on the components that go into a computer, the people who pick these components, the station that builds the computers, the operators who build them, the test information, the boxing lines, the peripherals that go along with the computers, the operators who pick and pack them, and the operator who inspects the finished computer etc.

This legacy software is supposed to back up the data on an Oracle database running on the Windows NT operating system, almost on a real time basis. The work-in-process (WIP) inventory reports are generated using the data available in the Oracle database. The expeditors in the factory area use these WIP inventory reports to track computers that are moving along rather slowly compared to their counterparts in the same order and help push them along faster. The backup task has a much lower priority compared to the tasks associated with moving and tracking computers in the factory. During times of normal demand, data are backed up every one or two minutes. However, when the factory demand increases (towards the end of the quarter), the backup task happens only once or twice a day. This means that the WIP inventory reports can be rather old. This affects the expeditor's tasks especially at a time when their services are greatly needed.

The distribution and shipping areas of the Optiplex factory use a new piece of software. This software program has a one-way communication link with the software system used in the computer manufacturing area. This one-way link works well in normal modes of operation. In the case of exceptions (e.g. missing systems), the software in distribution and shipping cannot track the missing computers and alert the manufacturing personnel to expedite those systems.

Thus, as Figure 5 indicates, the communication between the different layers is not seamless. Often communication involves transfer of critical data between the ERP layer and the control layer directly. This often slows things down, as the ERP system handles multiple factories.

To summarize, the challenges posed by the information technology systems used in the Optiplex factory are:

1. IT systems, developed over the years, cannot be scaled to facilitate the high volume of data and information flows;
2. Information sharing between various systems is designed to be at the ERP level and not at the control layer or MES layer; and
3. Centralized architecture of IT systems limits the speed and direction of data flows between them.

### 2.6.3 ORGANIZATIONAL ASPECTS AND CHALLENGES

The factory and the distribution centers have been traditionally housed in different buildings. The factory typically ships finished computers to the distribution center, where the computers are accumulated until a customer order is completed. Then, the distribution center ships the completed orders to the end customers.

The factory and distribution have different business metrics. Factory metrics monitor individual computer systems, where as the distribution and shipping center metrics track entire customer orders. In other words, a factory treats all systems the same, while distribution and shipping functions treat systems as being part of customer orders.

Additionally, the factory and distribution center have been managed differently in earlier Dell facilities. Factory being two steps removed from the customers is more internally focused compared to the distribution and shipping centers, which are one step removed from the customers. Business processes and problem resolution in both the areas are typically designed to achieve local optimization within the individual functions. Even though the new factory brings together both assembly and distribution areas inside the same building, many business processes are managed as if they are disparate entities.

In new Optiplex factory, the computer assembly groups have to work closely with the distribution center personnel to meet the factory's business objectives. However, it is often difficult to define ownership and responsibility for some issues, as they affect both the assembly and distribution functions.

To summarize, the challenges arising from the organizational aspects of the Optiplex factory are:

1. Different physical locations of factory and distribution centers in earlier Dell factories continue to remain as barriers in people's minds in the new factory;

2. Factory and distribution center do not have a clear understanding of each others' metrics and priorities;

3. Business processes of the groups are designed to optimize locally within each area and not optimize the operations as a whole; and

4. Ownership and accountability of all problems are not clearly defined.

### 2.6.4 SYNOPSIS OF MANAGEMENT MODEL AND CHALLENGES

The Optiplex factory has a very complex order fulfillment process, which needs greater collaboration across all the sub-areas inside the factory. It relies on more software systems and controls. This factory also needs globally optimized end-to-end solutions for its optimum functioning. Its design throughput is much higher than other Dell factories. This high velocity manufacturing demands high velocity decision-making to address problems affecting the line, and high velocity mobilization of resources to execute the decisions collaboratively.

However, the functional areas of the Optiplex factory are managed somewhat independently even though they are housed inside the same building. Each functional area continues to operate in isolation using the tools and methods from earlier facilities. This leads to sub-optimal management of the factory, especially in the face of increased throughput and extremely low amounts of work-in-process (WIP) inventory throughout the factory. Challenges arise from inconsistent business performance metrics, different management approaches, rigid information technology architectures that are not scalable, and from different mindsets of personnel in the different areas of the new Optiplex factory.

As a result, the hybrid approach of using traditional line-of-sight management in the front end of the factory and a centralized management from a control center in the backend of the factory does not scale effectively in this new and complex factory.

## 2.7 SAMPLE ILLUSTRATIONS

This section illustrates some examples of the problems and how they are addressed in the existing management system.

### 2.7.1 EXAMPLE 1 – COMMUNICATION BETWEEN ASSEMBLY AND DISTRIBUTION AREAS

Even though physically accommodating the front end and the back end of order fulfillment process inside the same building is a first step in virtual integration, there are several opportunities for improving the communication links that exist between the two disparate functions. This example points to a problem arising from communication problems between two processes in the Optiplex factory.

A typical customer order at the Optiplex factory has 'n' individual computers, and their associated peripherals. Systems when built, tested and boxed leave the assembly area into the distribution area. As the systems move into the order accumulation area of the distribution side of the factory (as shown in Figure 3) in conveyors, they are held in storage racks until all systems belonging to an order reach the accumulation area. Once an entire order is ready, all the systems are released from the accumulation area to the shipping area.

Often due to variability of processing times in the assembly cell or the test cells, one or two computer systems belonging to an order get delayed compared to their counterparts of that order. The almost complete orders are held in the accumulation area as they are awaiting the last one or two systems to join them. Due to lack of seamless communication between the various IT systems, the software package used in the distribution and shipping areas can not automatically create a list of these orders and alert the manufacturing personnel to expedite these computer systems. Instead, an operator manually performs this task by entering the information on computers delayed in the process in to the software program. Due to sheer volume, the number of orders missing one or two computers is almost always more than what one person can manually track and enter in the system. The order completion coordinators in the assembly areas prioritize this manual list of computer systems based on time the order has been started. These coordinators manually check the test cells, conveyors and the boxing areas to locate the systems. Once they locate the systems, they troubleshoot the reasons for the delay and expedite the systems.

This process has several problems. First, the IT systems used in the accumulation area cannot automatically generate a list of orders with one or two systems missing or communicate seamlessly with the IT systems used in assembly area. Further, the IT systems in the assembly area cannot precisely indicate the location of the systems in real-time. They can only track the last location the computer was scanned. This location has to be generated from a WIP report, as explained in section 2.6.2. Second, the person who generates the list passes it on to another person (order completion coordinator) who tracks down the missing systems and works on expediting the missing systems. Lack of automation and communication links between the software programs necessitate these handoffs, which are often sub optimal. Third, the prioritization done by order completion coordinators may not be the same as what is required from the order-level perspective. This difference creeps in due to the difference in order-level and system-level metrics used in different parts of the factory. Fourth, due to the high volume of systems handled by the factories, order completion coordinators are often working with a list that is three or four hours old. Many of the systems in their list may have moved from the time the list was originally generated. Fifth, due to the time delays and inefficient handoffs in the process, there is often not much visibility and transparency to the process.

### 2.7.2 EXAMPLE 2 – CENTRALIZED AND LOCALIZED DECISIONS

This example illustrates the problems arising from centralizing all the decisions in the back end of order fulfillment process in the control center at the Optiplex factory.

Pallet build area is in the shipping region of the Optiplex factory, where the orders that are released for shipping are palletized. Orders released from the accumulation area travel through a series of conveyors and are routed to free pallet build area. The pallet build area has several pallet build stations. The software package handling the backend processes has an algorithm that decides the number and type of systems that go to each pallet build station.

The pallet build area is a bottleneck in the factory. Therefore any delays in palletizing an order slow down the shipping area of the factory, and should be resolved very quickly.

Sometimes, systems released from the accumulation area get misrouted or mis-scanned and they will not make it to the appropriate pallet build area. Such incidents will delay the palletizing of computers belonging to an order. Since the shop floor operators typically get a steady stream of orders based on decisions made in the control center, they do not necessarily call the control center to notify them of the delays or go looking for the computers that are supposed to be coming to their pallet build stations. Instead they ignore these problems, continue to wait for the systems to reach their stations. This lack of information flow from the shop floor operators to the control room personnel about the misrouted or mis-scanned computer systems further aggravates these delays.

In the existing management approach, control center personnel senses these delays based on the slowdown in output from a pallet build station. They then have to locate the last scan of the missing systems and figure out potential causes for the problem. Once the control center personnel identify the problem, they have to call the shop floor operators and change their work instructions accordingly. Usually, they have to request one of the shop floor operators to manually find the missing systems on the mis-scanned systems lane.

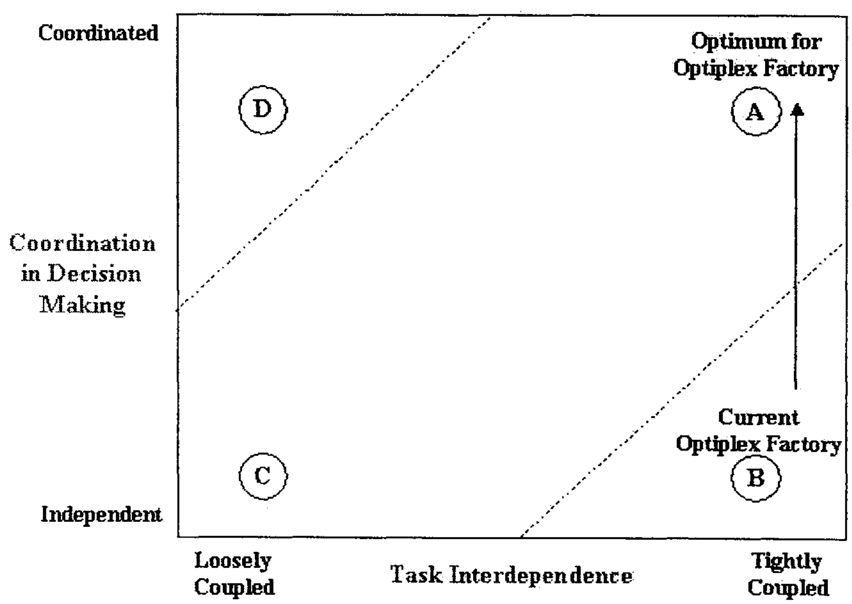
This considerable amount of delay arises from the lack of two-way communication between control room and shop floor operators. This delay will hold up not only the pallet build areas, but also the trucks at the shipping doors. Thus, under the current management system, when one or two computer systems are misrouted, it can add considerable delays to the shipping process, and can reduce the daily shipment volume of computers from the factory.

These two examples illustrate some issues with the current management system at the Optiplex factory.

## 2.8 PROJECT DEFINITION

Revisiting Janice Klein's research, operations that are tightly integrated work well when decision-making is coordinated across the areas [8]. The new Optiplex factory, with its tightly linked supply chain, is managed by a hybrid of localized management and centralized management without a high degree of coordination. As indicated in Figure 6, the Optiplex factory is in the lower right quadrant of the diagram (marked B). Based on Klein's conclusions, Optiplex factory's optimum location in the above diagram is in the upper right quadrant (marked A), where tightly coupled operations can be managed in a coordinated fashion.

**Figure 6: Optimum Coordination for Optiplex Factory Decisions**




This movement to the upper right quadrant to achieve such coordination in the complex Optiplex factory represents a new management system. This thesis is an effort to develop such a new management system. It defines a collaborative decision support system that is custom developed for the Optiplex factory, where decisions that affect multiple process areas can be made centrally and in an integrated manner. The thesis envisions such a collaborative decision support system in the form of an operations control center, where a dedicated set of people monitor the factory, identify problems as soon as they arise, make decisions in a coordinated manner, and mobilize resources across the factory to execute these decisions.

The project involves benchmarking control rooms in other industries to learn from available best practices. It then develops the architecture for the operations center for the Optiplex factory, including specifications of business processes, facilities design and layout, as well as system-level information technology design. The proposed architecture encompasses all aspects of the Dell factory, namely, order scheduling, raw material delivery to factory from supplier warehouses, computer assembly, boxing the computers, distribution and shipping. This thesis also develops a business case for the centralized operations center for Dell's discrete manufacturing process.

## 2.9 PROJECT APPROACH

This thesis describes the project in three phases.

1. The strategy phase is comprised of the opportunity identification part of the project. Sections 2.4, 2.5, 2.6 and 2.8 describe the strategy phase.

2. The design phase involves developing the architecture of the new management system. The design phase is broken down into two components – benchmarking of other industries and internal architecture design. The project develops the architecture of the centralized operations center in the following three threads:

    a. Business processes,

    b. Facilities, and

    c. Information technology.

   Chapters 3, 4 and 5 describe the design phase of the project. Specifically, chapter 3 talks about the benchmarking effort. Chapter 4 describes the architecture design of a decision support system at the Optiplex factory. Chapter 5 discusses the financial impacts of the project.

3. The implementation phase describes ongoing implementation of the solutions developed. This phase of the thesis also describes some of the organizational aspects that helped and hindered the project. This is discussed in Chapter 6.

## 2.10 SUMMARY

This chapter describes Dell Computer Corporation's background and its competitive advantages. It outlines the corporation's vision of using virtual integration to further its revenue and profit growth going forward. A key requirement for such virtual integration is a culture that encourages seamless sharing of information internally between the various functions in the value chain and externally between the company, its suppliers and its customers. As a case study for virtual integration, the thesis then describes a new factory designed to build the high volume Optiplex line of computers. The new factory is a first step by Dell to explore this virtual integration strategy. As a result, factory integrates all functions of order fulfillment from order scheduling through shipping inside the same building. The chapter discusses the salient features in business processes, information technology systems and organizational aspects at Dell in general and at this new factory in particular to bring out some of the challenges in achieving the corporate vision of virtual integration. The processes in the new factory, though tightly interdependent, are managed using two different approaches – localized line-of-sight management of computer assembly functions and centralized management of distribution and shipping functions via a control center. These two management approaches do not facilitate much coordination between all functions of the supply chain.

This project proposes an improvement in the coordination of functions inside the factory through integrated decision-making by re-defining the mission of the existing control room in this factory. The project attempts to learn best practices in business processes, facilities and information technology systems by first benchmarking other companies. It then aims to adapt the lessons learned from the benchmarking effort to redesign the internal business processes, facilities and information technology architecture to achieve collaborative decision-making in the new Optiplex factory.

# 3 BENCHMARKING AND LESSONS LEARNED

## 3.1 CHAPTER OVERVIEW

This chapter discusses the benchmarking effort aimed at identifying the best practices used by industry leaders in centralized control systems. Manufacturing and service industries are benchmarked along the three threads of business processes, facilities and IT architecture. Within manufacturing, benchmarking covered both discrete and continuous manufacturing industries.

The industries visited are:

1. Federal Aviation Administration,
2. Airline,
3. Chemical Manufacturing,
4. Automotive Assembly, and
5. Beverage Bottling.

This chapter describes the business processes, facilities and IT architecture of the above industries and draws some conclusions for Dell's operations center design.

## 3.2 BUSINESS PROCESSES AND ORGANIZATION

The business processes and the organizational structure at each of the five industries are presented in this section. The section also describes the five criteria that emerge from the benchmarking effort in determining whether decisions are centralized or localized.

### 3.2.1 FEDERAL AVIATION ADMINISTRATION

The Federal Aviation Authority's (FAA) regional Air Route Traffic Control Center (ARTCC) controls air traffic above an altitude of 14,000 feet in a region of the US airspace. There are twenty regional ARTCCs in the US. Each center monitors individual airplanes in its air space based on the response from the airplane's transponder. The center is responsible for avoiding any collisions mid-air. Collisions are avoided by either keeping the airplanes at the same altitude apart by more than five miles or by maintaining altitude separation of 1000 feet between adjacent airplanes.

The airspace covered by this center is divided into eight bays. Each bay is again divided into six sectors. An air-traffic controller monitors the airplanes in each sector. The controller communicates with the pilots of airplanes in his (her) sector to avoid any conflicts. The air-traffic controllers in each bay report to an area supervisor. Thus, there is an area supervisor who manages each bay.

Additionally, there is a traffic management department, which is responsible for monitoring air traffic four to five hours ahead as well as weather patterns. This department makes 'not-so-tactical' traffic decisions. A traffic management supervisor heads this department.

A watch supervisor heads the en-route air-traffic control center. Area supervisors who manage each bay report to the watch supervisor. The traffic management supervisor also reports to the watch supervisor. Thus, the watch supervisor is the ultimate authority in the control center. He (she) can draw on any resources from his organization in the control center, to address issues and resolve any conflicts.

### 3.2.2 AIRLINE

Airline control centers are set up due to FAA regulations. The control centers manage aircraft dispatching, aircraft routing and re-routing, and weather monitoring functions. In addition, the centers manage maintenance and security monitoring functions. They also act as response centers in the event of an airline accident.

Aircraft dispatchers are responsible for both operational as well as operations aspects of the airline's flights. Operational aspects include FAA compliancy and regulatory issues, namely safety, comfort of the planned ride, etc. Operations tasks deal with economic aspects of the flight, e.g. amount of fuel to fill in a plane. Alternately, the dispatchers' tasks can be classified into flight planning and following. Flight planning includes tasks such as selecting routes, deciding on the amount of fuel to fill, etc. Flight following deals with any deviations from plan due to weather, air traffic control constraints, navigation aid problems, flag, off-schedule landing, etc. The dispatchers manage communication with the pilots from push off at the departure gates to arrival at the destination gates.

Aircraft routing deals with a dynamic optimization problem that takes into account the capacity of planes, their maintenance schedules, flight schedules, projected demand on the routes, weather patterns, as well as schedules of pilots and crewmembers. There is a constant re-routing function that deals with variations in these factors ultimately aimed at optimizing the airlines' performance metrics.

Additionally, the center has weather monitoring, maintenance engineering, and security monitoring functions. The center also has regional managers responsible for the airline's flights in the various sectors of the country.

A shift duty director heads the control center. The air traffic controller, maintenance manager, and sector managers report to the duty director. Although some of the supporting organizations may not report directly to the shift duty director, he (she) has ultimate authority to tap any organization to support resolution of performance issues.

### 3.2.3 CHEMICAL MANUFACTURER

The chemical manufacturing company benchmarked in this study manufactures a powder through a series of batch processes. The manufacturing plant uses distributed control systems (DCS) to control the various manufacturing processes. The controls used in this plant are made by Bailey and by Honeywell. The plant has a central control room and two auxiliary control rooms.

A corporate group is responsible for setting the company's overall vision for process control. This corporate group, however, does not have direct ties with the individual business units. The process control consultants of this corporate group do not set corporate wide standards for control systems that individual factories should use. The local management in individual factories and business units is typically responsible for selecting, installing and maintaining control systems to support their operations. Until 1990, this company did not specify firm-wide standards on which control system vendors to use. In the 90s, most of the factories of this company started using DCS made by Honeywell or Bailey.

A director of operations manages the plant. A plant manager reports to the director. Unit managers for operations, maintenance, and research & development report to the plant manager. Process control is managed within the operations group. The process control leader, reporting to the unit manager for operations, is responsible for the distributed control system of the facility. He (she) acts as a single point of contact for hardware, software, applications and control aspects of the control centers of the factory. DCS technologists report to the process control leader. DCS technicians, who work for the technologists, are experienced operators with expertise in various areas of the plant and its operations. There are two technicians in the central control room, and one technician each in the two auxiliary control rooms.

One of the auxiliary control rooms is the loading control room. This room is responsible for order tracking, accounting, inventory management and such functions. This control room feeds the plant output data to a centralized SAP/R2 system.

### 3.2.4 AUTO MANUFACTURER

The auto manufacturer benchmarked in this project produces over 500,000 vehicles and 500,000 engines annually at the facility visited. The 2 million sq. ft. facility employs 8000 people in a non-unionized plant. The production floor is divided into three regions – Body and Weld, Painting and Assembly. The plant has three control rooms – one for power train and one for each of the two assembly areas. Benchmarking effort studied the production line control room that manages the assembly schedule for one of the assembly lines of the factory. It has three technicians and a manager.

The role of the production line control room is to determine overtime needed on a daily basis, given the demand and actual production volumes. The control room reports the daily and monthly production volumes, and inventory in each of the three regions. It also reports the inventory in between these three regions. The automotive manufacturer uses a system called the assembly line control (ALC) to monitor the individual vehicles as they move through the factory. The ALC system scans vehicles at each workstation, as well as gives work instructions to robots – what type of car is it and what to do with it - at every station. Each vehicle has a microwave tag that keeps track of the workstations that the vehicle passes through during its manufacturing and assembly steps. This information is used for quality control purposes.

### 3.2.5 BEVERAGE BOTTLER

The beverage bottler's unionized-plant produces several million bottles and generates sales revenues of a few million dollars annually. The plant occupies over 150,000 sq. ft, and produces over 100 stock keeping units (SKUs). It employs a total of 75 employees.

A director manages the plant. The director is also responsible for maintaining and monitoring the computer integrated manufacturing system that monitors the operations of the bottling facility. In fact, the director has designed and developed the system from scratch with very little support form corporate IT resources. The system monitors downtime and throughput of the facility. These data are available at various locations through out the plant.

### 3.2.6 CONCLUSIONS

A recurring theme across all the operations control centers is a clear understanding of the centralized business processes that are managed from within the central control room vs. the de-centralized processes that are managed close to the operation itself.

In cases where there is a cross-functional group residing in the operations control center, a single person is recognized as the ultimate authority during every shift. This person can direct resources regardless of reporting structures.

The benchmarking effort identifies five dimensions or factors that need to be considered in deciding whether a process should be executed within the operations center or is better managed in a de-centralized manner local to the operation.

**Business Impact.** The business processes managed through the operations center typically have a high impact on the major factors that influence the performance of the business.

**Response Time.** The business process response time should improve by having the process managed through the operation center. A common theme across all of the operation centers visited is an emphasis on response time; i.e. all decisions that are managed through the centralized control center need rapid response time. This factor by itself may not be a good reason to have the process managed through the operation center. This criterion needs to be evaluated in conjunction with the other factors.

**Information Input.** If a business process requires information input from a wide range of sources or different functional groups, then it might be a good fit for the centralized operations control center. To some degree an "ideal" IT system could consolidate all of the information for local access and decision making, if this was the only factor that drives the process into the center. However, the "ideal" IT system often is not in place.

**Decision Makers.** If a business process requires collaboration of a cross-functional team of decision makers to optimize the business results or understand all the constraints, then it is a good candidate for centralized decisions. This is very apparent in the airline operations center where many constraints (i.e. pilot schedules, crew schedules, aircraft maintenance, weather, etc.) handled by different functions have to be considered in the decision process.

**Decision Output.** If the results of a decision affect a wide range of resources and require cross-functional coordination and execution, then it may be a good fit for the operation center. A safety alert or plant evacuation process as observed at the chemical manufacturing facility is a good example of a process where the decision output needs coordination and execution from an operations control center.

In all cases, the business processes and organizational structure in the operations center support the processing of large amounts of information to make rapid, collaborative decisions. The types of business processes managed by the operations control center demand the processing of a wide scope of information. These processes dramatically influence the business performance of the respective operations.

The business functions supported by the control center are clearly defined at the FAA, the airline control center and the automotive assembly plant. In all these locations, the roles of the individuals and the organizational hierarchy support making rapid decisions collaboratively.

## 3.3 FACILITIES

This section describes the facilities layout in the benchmarked industries. The details of each facility are first discussed, followed by some observations.

### 3.3.1 FEDERAL AVIATION ADMINISTRATION

#### *3.3.1.1 Facilities Layout*

The FAA ARTCC is housed in a rectangular building, with the entire control office being divided into eight bays. Each bay supports an area. Each area monitors six sectors (of airspace). There is a central aisle that connects all the bays. The watch supervisor's office is in a bay that is located at one end of the control center. Across from the watch supervisor bay is the IT support bay. The next set of bays is for traffic management. Each bay has six air traffic controllers. These air traffic controllers manage what is called an area. Each bay is led by an area supervisor. The area supervisor's desk is towards the central aisle. This gives the supervisors easy access to not only the air traffic controllers in his (her) bay, but also to the adjacent bays and to the watch supervisor's bay.

The facilities layout attempts to reduce noise level and provide a comfortable working environment. There are sound absorbing pads hung from the ceiling. They mentioned that they actually preferred the old control room layout where the watch supervisor had a better line-of-sight to all of the workers. The current "bay" layout combined with the height of the consoles eliminates line-of-sight management.

#### *3.3.1.2 Display Technology*

Display technology is based on standard X-Windows display management software, which enables ease of integration with new flight data applications and automation. There are four types of consoles that are used by the ARTCC. They are Radar, Data, Assistant consoles and Ghost Pilot workstation.

Each air-traffic controller has a Radar console (R-console). It has three monitors – one 20 inch by 20 inch color CRT monitor in the center, and two mini-monitors on either side. The CRT displays information on each aircraft being monitored by the controller. There is a central keyboard associated with the CRT. The mini-monitors display the voice switching and control system (VSCS). Above the CRT is a backlit display holder that houses the airline routes published by the FAA. This is a static display that gives an overall view of the routes.

To the right side of the operator is a data console (D-console). The data console has a 15-inch diagonal CRT, and also has strip holders. The strip holders hold paper-strip cards about the planes being monitored by the controller. There is room for roughly 30-35 strips.

There is also an assistant console (A-console), which is similar to the D-console in design. The Ghost Pilot workstation is to the right of the A-console. The purpose of the Ghost Pilot workstation is to support training operations.

#### *3.3.1.3 Communications*

The desks have two headsets on either side of the controller's desk. The wiring of headsets allows for two people to listen to the same conversation. This reduces the need for speakerphones. Most of the communication is with the pilots. In case of emergencies, an audible alarm alerts the controller, as well as the area supervisor. If two planes are on a collision course, then the watch supervisor is also notified by the system.

#### *3.3.1.4 Console Ergonomics and Design*

The air traffic control center's consoles were designed under a contract with McDonnell Douglas. The facility also had some consoles manufactured by Wrightline for some of the support functions such as weather and IT services.

The monitors are placed at an angle to reduce glare. The headsets reduce the noise level from the pilot-controller communications. Most of the noise seems to come from the movement of the plastic flight strips on their holders. The management team wants to further reduce the noise level.

### 3.3.2 AIRLINE

#### *3.3.2.1 Facilities Layout*

The airlines' operations control center (OCC) is a U shaped facility occupied by over 100 people. The bridge portion (that links the two long edges) houses the duty director, the chief maintenance officer and the sector managers.

#### *3.3.2.2 Display Technology*

The control room has seven 12 ft. by 8 ft. screens that project images from projectors. The projectors reside behind the screens and mirrors are used to reflect the image onto the screens. The projector room is about five feet deep, behind the screens. The projected images can be viewed from very close to the screens or at wide angles without any distortions. The screens display not only current status of schedule compliance, but also weather and news from TV. The screens are located in the bridge area of the control room.

In addition, there is a conference room adjacent to the operations control center. That room has a smaller screen (8 ft. by 6 ft.), which also displays an image projected from a projector. The space used by the projector behind the smaller screen is only about two feet deep.

#### *3.3.2.3 Communications*

Headset enabled telephone systems used in the control center allow for efficient communication between dispatchers and the pilots without excessive noise. Despite housing over 100 people in the OCC, very low noise levels are achieved via sound absorbing walls and ceilings.

#### *3.3.2.4 Console Ergonomics and Design*

Evans Online has designed the consoles in this control room. The consoles have two or three 17" CRTs, and a high-speed telephone. The telephones in some cases include a touch screen display. The CRTs are placed at an angle behind anti-glare glass. The consoles have height-adjustable desktops with adjustable lighting. The consoles are wired for headsets, so that a dispatcher only needs to hook his (her) headset into the console. There is a set of two lights on top of the console to indicate the telephone status.

### 3.3.3 CHEMICAL MANUFACTURER

#### *3.3.3.1 Facilities Layout*

The central control room of the chemical manufacturer is designed for abnormal operating conditions. It is a rectangular room with two sets of consoles. The consoles face a wall that has six TV monitors. Each set of consoles has a bank of ten (5 wide by 2 high) CRTs, designed by Honeywell. Of the ten CRT monitors, three screens are used for controlling processes. A fourth screen is used to display an alarm summary. The rest of the screens are used to display data trends. However, any of these screens can display any information, and the displays are customizable by individual technicians.

One technician manages the upstream processes, while the other manages the downstream processes. There does not seem to be much communication between the two technicians in the room.

#### *3.3.3.2 Display Technology*

17" CRT monitors are being used in the bank of consoles. These monitors are provided by Honeywell, and are encased on special casings. Due to these special casings, it takes more than two days to change monitors. The screens are touch-sensitive, and can be controlled without using a mouse. These consoles use a special keyboard, also designed by Honeywell.

#### *3.3.3.3 Communications*

The technicians use a PA system to make announcements to the floor operators, who check the status of valves, etc. They also use two-way radios to communicate with floor operators. In addition, the technicians also use a telephone to communicate with their management teams. The technicians have the authority and the ability to quickly shut down the facility in case of emergencies. They do not need to wait for their management approval for shutting down the facilities in emergency, as safety is a key concern.

#### *3.3.3.4 Console Ergonomics and Design*

The consoles are slightly curved, giving the technician good visibility and access to all five monitors. Noise levels do not seem to be an issue.

### 3.3.4 AUTO MANUFACTURER

#### *3.3.4.1 Facilities Layout*

The auto manufacturer's production line control room is a rectangular room, which houses three technicians and a control room manager. The room is well lit, and is located on the second floor of the building. It does not have direct line of sight of the entire operations. The room is simple in its appearance, and does not use any high technology equipment.

#### *3.3.4.2 Display Technology*

The auto manufacturer uses a white board to display planned and actual production volumes in each shift, for two weeks at a time. It also has a television displaying key metrics on inventory, throughput and overtime. Further, Allen Bradley control panels display key metrics on operations rate, amount of overtime and cumulative throughput through body and weld, paint and assembly lines. The production data on each shift is also available on the company's intranet, on daily and monthly bases.

#### *3.3.4.3 Communications*

Communication between the team members and the assembly lines or paint shop seems to be via telephone. However, the room is not noisy.

#### *3.3.4.4 Console Ergonomics and Design*

The control room has regular desks and desktop computers.

### 3.3.5 BEVERAGE BOTTLER

#### *3.3.5.1 Facilities Layout*

The beverage bottling facility uses a control room to track downtime and throughput. The control room is a small rectangular room. It has two servers running RSView software that monitors the control systems of the facility. There is one person in the control room, who monitors the system downtime and throughput.

##### *3.3.5.2 Display Technology*

There are five Allen-Bradley control panels on the plant floor, which can display the same information as the computer in the control room.

##### *3.3.5.3 Communications*

Communications are handled via a telephone to the appropriate area in the plant. Noise levels do not seem to be an issue.

##### *3.3.5.4 Console Ergonomics and Design*

The control room at the beverage bottler is extremely simple in its design. An office desk is used in the control room. No special attention has been paid to ergonomics, except that the control room located on the second floor has glass windows that over look the plant floor.

#### 3.3.6 CONCLUSIONS

All the companies use a separate room for their control centers. The layout of the rooms follows the flow of operations. There are different levels of sophistication between the different industries. Some industries house everyone responsible for its operations inside a state of the art control room, where as some others use a small number of people to manage its operations from a centralized location. The functions performed are nonetheless effective.

## 3.4 INFORMATION TECHNOLOGY ARCHITECTURE

#### 3.4.1 FEDERAL AVIATION ADMINISTRATION

The ARTCC uses Display System Replacement (DSR) that provides a reliable computing environment. Reliability and high-availability are ensured through hardware redundancy, fault tolerant software design, and primary and backup networks. DSR is based on an open architecture, a distributed processing environment and a modular design to support future enhancements. It is uses commercial RISC processors running on the UNIX operating system. Console processors and network resources are designed to have at least 50% reserve capacity in CPU utilization, memory and hard disk storage. Local communication, enabled by four redundant IEEE 802.5 networks, provides the primary communication path from the host computer to the consoles. The backup communication network is enabled by IEEE 802.3 network. This provides the backup radar path from the Radar access channel to the R-position consoles.

DSR includes three major components. The first component is the operational DSR installed in the 20 ARTCCs to provide air traffic control functions. The second component consists of a DSR support system complex (DSSC) facility installed at the William J. Hughes Technical Center (WJHTC) in Newark, NJ, where DSR remote software maintenance and development is performed. The third component is the DSR technical support personnel training facility located at the Mike Monroney Aeronautical Center (FAA Academy). Wide Area Network (WAN) communications electronically link the WJHTC DSSC with both the FAA Academy and the 20 ARTCC DSR locations.

### 3.4.2 AIRLINE

The computer systems used by the airline to manage its control center runs on Windows NT. The servers are housed locally, inside the control center. The servers are connected via a dedicated network.

### 3.4.3 CHEMICAL MANUFACTURER

The control centers for the chemical manufacturer are run on dedicated computer systems and dedicated networks. Control systems do not use plant-wide IT networks used for desktop connectivity. As a result, control systems are not necessarily supported by IT service groups, which instead focus on desktop hardware and applications.

The systems run on Honeywell's proprietary operating system that is based on Windows NT. The hardware is locally resident and is independent of the plant wide network for email and desktop connectivity. Due to the widespread use of Bailey and Honeywell distributed control systems in the chemical manufacturer's facilities, the user groups at various locations learn about each other's systems and problems via news groups. Additionally, they have annual user-group meetings for information sharing and learning purposes.

#### 3.4.4 AUTO MANUFACTURER

The paint shop and assembly lines are controlled using Allen-Bradley control systems, while the body and weld shops use Toypa control systems. An Allen-Bradley control panel, inside the control room, displays key metrics.

#### 3.4.5 BEVERAGE BOTTLER

The beverage bottler's plant has a simplistic architecture for the control systems that monitor bottling plant's throughput and downtime. It runs on Windows NT, and uses separate servers to house the application and backup data. The system has its own network, and provides information about throughput and downtime to the plant director as well as to the plant floor operators. The salient feature of this straightforward approach is that the hardware is locally resident by default.

#### 3.4.6 CONCLUSIONS

In all cases, the IT applications and databases necessary to manage the execution of the operations center processes are installed and supported locally (i.e. over a LAN with resident IT support). These systems use a dedicated network to support the mission critical operations.

### 3.5 SUMMARY

Benchmarking industries in continuous, batch and discrete manufacturing, and in service industries allows Dell to learn about the operations of control rooms in these industries. Benchmarking also helps Dell examine how the control centers in these industries enable and optimize their business processes.

In all the industries visited, the operations that are either complex or tightly linked or both are not managed locally by line-of-sight. Such complex, tightly linked operations are typically managed from a central location that integrates decision-making across the entire process.

Based on the benchmarking effort, five criteria are identified to determine when a decision is centralized and when it is localized. These criteria are:

1. Business impact,
2. Response time,
3. Information input,
4. Location of decision makers, and
5. Decision output.

For any decision to be centralized the first two criteria have to be met, i.e. the decisions and the business processes managed in the operations center should have a high impact on the factory performance and require quick response. If not attended to, then these problems can escalate and affect the performance of the factory. Thus, decisions that need to be in the operations center should have a huge business impact and require rapid response.

In addition, decisions that are centralized have to meet at least one of the other three criteria. Information coming from different sources can be consolidated in the centralized operations center. Decisions that span multiple areas of the factory can be made more optimally in a centralized location. Finally, when the results of the decisions need collaboration with a wide range of areas within the factory, such decisions can also be best made centrally.

In other words, issues or problems that occur inside a process module (assembly area or distribution area) and do not affect other areas around it do not need to be centralized, unless they meet criteria 1 and 2 above. Issues that span multiple process modules typically need information input from multiple areas, and their solutions often affect multiple areas. Such efforts require mobilizing resources that span multiple areas. Further, such issues typically need some modifications in the normal process or scheduling decisions. These issues ought to be centralized.

All companies use dedicated hardware that is locally resident at the facilities and use a dedicated network. Some companies take a simplistic approach and house only the functions necessary for collaborative decision making inside the control room, whereas others house all the personnel involved in controlling its operations inside the control room. Either way, the roles of the personnel inside the control room are clearly defined and so is the organizational hierarchy.

# 4 ARCHITECTURE DESIGN OF COLLABORATIVE DECISION SUPPORT SYSTEM

## 4.1 CHAPTER OVERVIEW

> *"No core process redesign will work effectively unless the solution spaces for all these different kinds of change can be at least roughly aligned. Technology can help, as an enabler of behavioral and managerial change, but it is not by itself anywhere near enough. Redesign is not an IT exercise [12]."*

This chapter discusses the architecture design of the new collaborative decision support system developed during this project for Dell's Optiplex factory. This design adapts the lessons learned from the benchmarking effort to the specific business conditions and operational practices of Dell. This chapter is organized into three threads: business processes, facilities and IT architecture.

## 4.2 BUSINESS PROCESSES

This section redefines the business performance metrics and the business processes to be managed within the operations center of the Optiplex factory. The five criteria developed from benchmarking namely, business impact, response time, information input, location of decision makers and decision output are used in redesigning the business processes at Dell's Optiplex factory.

### 4.2.1 BUSINESS PROCESS REQUIREMENTS

The business performance metrics have to be standardized to include both system-level and order-level information. The existing metrics track only systems-level information on throughput and inventory. However, from a customer's view, order-level information is more relevant. With the existing metrics focusing on system-level details, it is difficult for the organization to track order-level information easily. Tracking order-level throughput and inventory information will help the organization shift its attention to a more customer centric view. It will also reduce the cycle time of an entire order in the factory.

Further, the metrics have to be collected in a consistent way across the factory to ensure real time consistency.

Another lesson from the benchmarking effort is to monitor all the aspects of the business processes within the operations center. Again, at the existing control center at Dell, the people focus only on the backend of the order fulfillment process. It also has one person from the production control team, who schedules orders. The front end of the process is managed by localized line-of-sight approach. This hybrid approach does not optimize decisions throughout the factory. The tight-knit processes necessitate that the entire operation be managed from a centralized location to make globally optimized decisions encompassing all different areas of the factory. This requires an expansion of the functions currently handled inside the control room.

Based on benchmarking, an operations center should accommodate all the decision makers inside the same room. The decision makers should also have the authority to make decisions. These steps ensure quick decision-making and resource mobilization for rapid execution of the decisions. As described in Chapter 2, this is not the case at Dell's current control center. The existing control center at Dell is staffed with people who are fairly knowledgeable about the distribution and shipping areas. Based on some criteria, they decide which orders are to be shipped. The control center operators essentially walk orders through the distribution and shipping areas of the factory. However, when it comes to bigger decisions on exception handling, these operators are not experienced and empowered to make the calls. Such issues are often escalated to senior management inside the factory, and are not resolved in a timely manner.

### 4.2.2 BUSINESS PERFORMANCE METRICS

This section redefines the business performance metrics with a view to optimizing the entire order fulfillment process at the Optiplex factory, as per the requirements stated earlier.

Based on interviews with various members of the management, supervisors and control room personnel, the important metrics previously monitored by each area of the factory are identified. In addition to the existing metrics, some new metrics are introduced to track order-level information on throughput and inventory. The new design also standardizes the methods used to obtain the metrics. These metrics are then grouped into three major categories – throughput, inventory and quality.

**Throughput.** Throughput is one of the key indicators in Dell's order fulfillment process. However, the throughput numbers do not make sense as absolute numbers due to the variability in customer order profile. So, the order fulfillment process at Dell prioritizes the orders so as to achieve 100% on-time delivery of computers. The throughput numbers should be used along with the information on customer's expectations on delivery date. These throughput numbers at a system-level and order-level from the various process steps within the factory can be used along with the work-in-process inventory at these various steps to identify bottlenecks, starvation, utilization of the bottleneck and other resource allocation issues.

**Inventory.** The inventory metrics focus on work-in-process (WIP) inventory of computers at various process steps. This information can be used in several ways. For instance, capturing the WIP inventory in assembly helps production control decide how to allocate the various workstations in the scheduling process. The kitting area uses this information to decide when to feed a line, how to divert kits to different lines, etc. Similarly, WIP inventory in front of the boxing area helps to determine any issues (parts, staffing, rate, etc.) at the various boxing lines. The best way to display distribution area inventory information is to display the shippable inventory as a fraction of the total inventory. Production control can use this data to allocate different types of computers or orders based on this information. Order completion coordinators (in the assembly area) can use this information to identify individual systems that are holding up an order. The operations center can prioritize the orders and dispatch a priority list updated in real-time to the order completion coordinators.

**Quality.** Quality metrics are currently captured independently at various parts of the plant. They are now obtained from kitting, computer assembly and test (statistical process control data), boxing (customer experience), and scanning and routing functions. This thesis recommends that the operations center should not view this data in isolation. Instead, it should tie together these data to monitor quality issues throughout the process. Further, by monitoring these data on a normalized scale, the operations center can easily identify the problem areas. This helps identify catastrophic problems before they occur. Additionally, quality data can be fed back to the area that caused the problem via screens available though out the factory. For instance, providing real-time feedback on build quality of computers to the technicians assembling the computers helps them understand how they are performing.

Also, it alerts them if they are doing something wrong or if the incoming parts have quality problems. This awareness will help them catch problems before the computers leave their area. This reduces the cycle time of the process, and improves the overall product quality.

### 4.2.3 BUSINESS PROCESSES

> *Someone—a "process owner"—whose responsibility cuts across functional boundaries is now held accountable for the performance of a complete, integrated process [12].*

The factory processes require tight coordination between all the steps in the supply chain – from order scheduling to computer assembly through distribution and shipping – to ensure that problems affecting the line are attended to and resolved within 10 to 15 minutes for the line to continue operating. Thus, the new operations center design, proposed in this section, represents all the functions of the factory inside the same room. In designing the new roles and functions, redundant functions existing in the different process groups are carefully eliminated.

The description of job functions in the new operations center is dependent on the functions performed by the factory. It is important to note that these job functions need to adapt with changes in the order fulfillment process at the factory.

#### *4.2.3.1 Production Scheduling & Materials Management*

This function involves production scheduling, supplier warehouse planning, planning for components that bypass the supplier warehouses, as well as planning for systems that need special integration. This team of people works very closely with one another. In the proposed design, all four of these functions are represented inside the operations center. This team sets the pace for the rest of the functions. It needs to be constantly in touch with the assembly and the distribution areas to dynamically adjust production scheduling throughout the day to minimize downtime and to maximize utilization of equipment and people.

#### *4.2.3.2 Manufacturing Execution*

The steps involved in this section of the process are output monitoring between the sub-areas in this section, namely, kitting, build, test, and boxing; production WIP management; as well as real-time quality management. Output monitoring and WIP management functions are necessary to ensure that any bottlenecks in the overall process are not blocked or starved. The factory's business objectives and customer order profiles specify a throughput target for the day. Throughput requirements on an hourly basis for the individual areas are obtained from that number. Additionally, the factory design limitations impose conditions on the number of systems in the in-transit buffer between the three sub-areas in this section. (This in-transit buffer is actually comprised of space on the conveyors when the systems travel through the process. This is not a holding area for systems.) Manufacturing execution plays an important role in ensuring that the factory meets its business goals daily. Most of the issues that come up in this area affect the upstream production scheduling functions or the downstream distribution functions. Additionally, this area needs to work closely with the distribution area to monitor the individual systems holding up orders in the distribution center, and keep the order completion coordinators working efficiently.

#### *4.2.3.3 Order Accumulation & Shipping*

The roles of this process section represented in the new design of operations center are WIP inventory and cycle-time management, order-level shipping management as well as carriers and dock door logistics management. Currently, six people handle these functions inside the control room; it is estimated that four people can effectively perform these roles in the new operations center. Their role is to keep the dock doors operating optimally. Depending on the customer requirements on delivery date, customer location, and carrier options, different factory orders have different deadlines within the factory. The shipping and dock door management functions optimize the completed orders against these deadlines, so as to reduce the inventory in the overall system. Orders, accumulated in the automated storage and retrieval system, are released based on carrier availability, order deadlines and other criteria by the operations center. They monitor the orders from this point on until they are loaded onto the appropriate trucks.

These functions need to be tightly integrated with production and order scheduling areas to optimize the overall process.

#### *4.2.3.4 Support*

The support functions of maintenance, IT as well as the client assistance center for the factory are represented inside the operations center. Currently, when a piece of equipment fails or malfunctions in the factory, operators from the plant floor alert the maintenance personnel, and the problem is logged into their queue. Then someone from the maintenance department is paged, and that person attends to the problem based on its priority and its priority in relation to other problems in his/her list. By integrating the maintenance functions inside the operations center, the maintenance team can closely work with the other functions, monitor the equipment for problems and dispatch someone to work on issues even before they get a call from the shop floor. Also, by working with other areas in the operations center, they can proactively monitor equipment fatigue based on the trends, maintenance schedules, WIP inventory, and throughput rates. When they see a potential for problems, they can pro-actively divert systems off that conveyor and fix the cause of any potential troubles. This, when performed in co-ordination with order scheduling, production and distribution functions can minimize the impact of any equipment issues on meeting the business requirements.

Similarly, local support for IT systems that is specific to the machines and systems supporting production in the individual factories help address problems quickly and efficiently. This process also helps reduce the impact of any IT issues on meeting customer delivery deadlines. The client assistance center supports other problem solving activities for the factory personnel.

### 4.2.4 PERSONNEL AND FUNCTIONS

Having identified the business roles to be performed inside the operations center, it is important to assign the roles to people with appropriate background, skill sets and experience. Given the importance of the problems handled by the new operations center, the personnel should have the authority to make decisions. With the extent of cross-functional work occurring in the control room, the personnel chosen should have the ability to work well in teams and to influence others. Decisiveness is another skill that is deemed important to enable rapid decision-making. Exposure to multiple areas of the factory is another attribute considered. The background of the factory personnel is matched with the job functions in selecting the individuals for the various positions.

The production control area is ultimately responsible for ensuring on-time order fulfillment at the Optiplex factory. So, this re-design effort identifies a person from the production control area to lead the operations center. Two other people experienced with computer assembly and distribution areas are chosen to assist the production control leader in managing the new operations control center.

As mentioned earlier, the functions handled by the new operations center needs to adapt with changes in business conditions of the factory. As a result, the personnel chosen to fill these roles also have to be constantly evaluated against the job requirements to ensure good fit with the work functions as well as to enable smooth operations of the factory.

## 4.3 FACILITIES

In redesigning the facilities for the operations center, the best practices identified from the benchmarking effort serve as a baseline. Dell specific needs are then added to define a set of requirements for the Optiplex factory's operations center. Based on these requirements, vendors have been identified to build the operations center to Dell's custom specifications. This section describes the salient features of the facilities design.

### 4.3.1 FACILITIES REQUIREMENTS

The facilities design should be capable of supporting the business processes. It should allow all the business functions to be represented. The design should also follow the process flow to enable better communication flow. There must be dedicated space for separate meetings with larger teams when issues come up, without disturbing the operations center personnel from performing their normal functions.

The new design should provide a good working environment. This involves safety, ergonomic and acoustic considerations. Since people in the operations center are using their computer terminals all day long, special care should be taken to reduce their exposure to radiations from the cathode ray tube monitors of computers. The work surfaces and computer screens should be designed to provide a pleasant working environment.

The noise level in the control room should be low. The operations center should have sound absorbing walls and ceiling. The use of speakerphones and two-way radios is not allowed inside the operations center as they increase the ambient noise level.

Another requirement is to limit the traffic inside the operations center. Currently, during each and every minor issue, many people walk into and out of the control room. In addition, people come in to watch the updated WIP inventory and throughput numbers kept on a white board.

Additionally, there have been many occasions where the team could not find a meeting room to discuss problem-solving methods, when bigger issues came up. It sometimes takes up to three hours to find a conference room that can accommodate a large group of people.

### 4.3.2 FACILITIES DESIGN

The new design is shown in Figure 7. The design accommodates all the requirements mentioned in the previous section. The layout has all the work functions represented, and the layout of the functions follows the process flow, starting from the production controls and materials to shipping. The support functions are also included in the operations center.

The people managing the operations center sit at the center table. The center table can accommodate three people. All the work surfaces are pre-wired for headsets with connections to speakerphones and two-way radios. Further, the conference room across from the operations center can be used to meet with management and/or other larger teams.

The proposed workspace furniture layout is shown in Figure 8, as defined by a professional workspace design firm. All workspaces can hold two or three flat screen displays for the individuals performing the job. Additionally, the three screens on the wall display projected images. The people running the operations center can control the screens.

Figure 7: Proposed Facilities Layout of the Operations Center

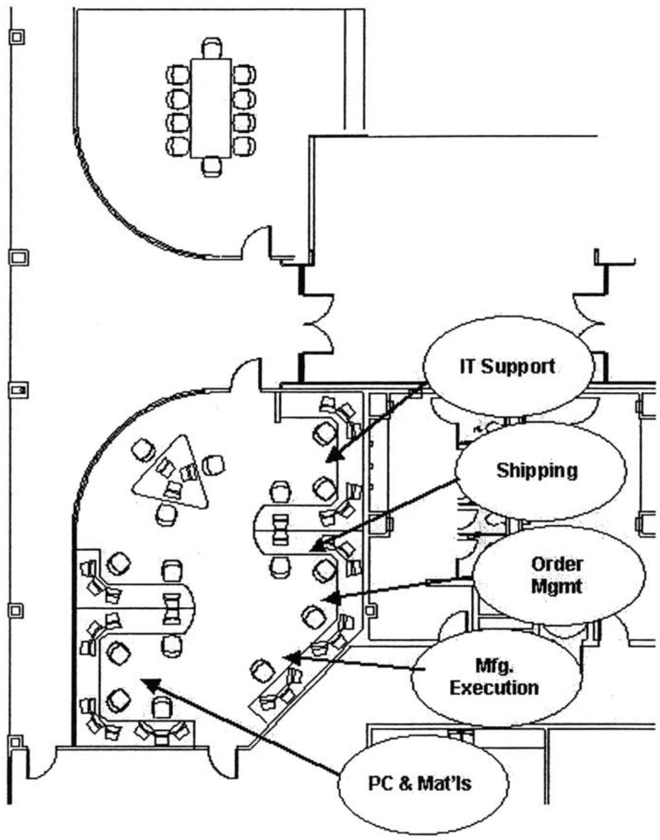
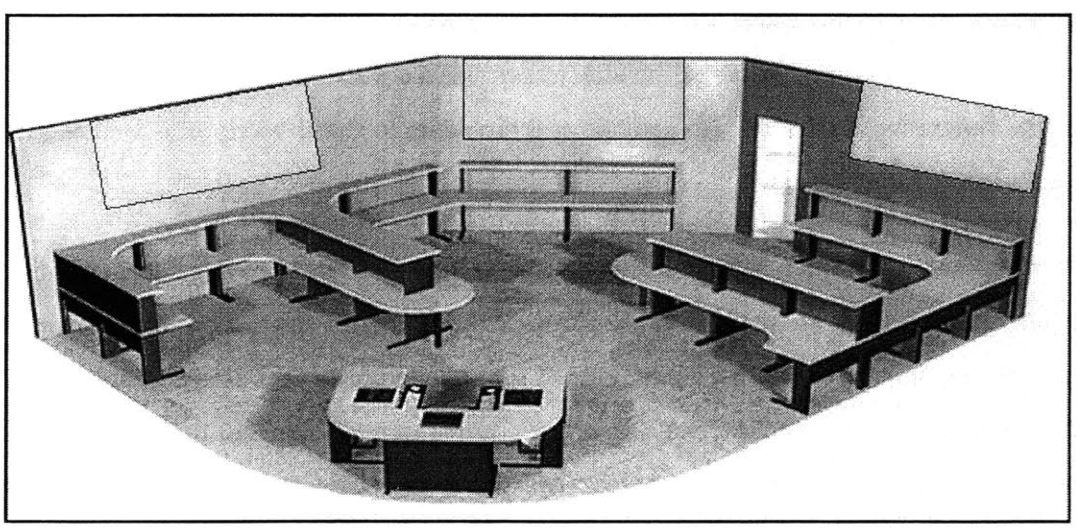



Figure 8: Proposed Furniture Layout of the Operations Center



## 4.4 IT ARCHITECTURE

This section describes the IT architecture requirements necessary to manage the operations center processes. It then proposes a system level design of the IT architecture that fulfills these requirements.

### 4.4.1 IT ARCHITECTURE REQUIRMENTS

The IT systems should provide reliable access to consistent, complete, current and correct data that is necessary to enable real-time collaborative decision support. Only then can the IT systems be reliably used to manage the factory.

Specifically, there must be local hardware to support the operations of the factory, with redundant capability to ensure continuity of data and information to the decision makers.

### 4.4.2 IT ARCHITECTURE DESIGN

The IT architecture should be able to support the above objectives. The design includes local hardware residing inside the factory to control all the applications necessary to run the factory. This reduces the load on centralized data storage. It also decreases the retrieval time of data. Redundant servers should be capable to picking up the operations in case of a failure of primary servers. The application servers, database servers and the data storage systems must be separate physical computers to improve the reliability of the overall system. The database programs and the storage functions are more CPU intensive and need to be separated so as to not cause any failure in the mission critical, non-CPU intensive applications. The system should be able to provide a consistent view of the operation across all the functions. It should also provide real time data to the shop floor as well as the operations center.

As discussed in Chapter 2, the current IT architecture does not provide most of these functionalities. This is largely because some of the functions are run on legacy mainframe computers, which control the operations in multiple factories that are geographically dispersed around North America. Also, the control layer software in the factory floor does not communicate with the control layer software in the distribution and shipping areas. This necessitates data transfer from one ERP system (that handles manufacturing) to another ERP system (that handles distribution and shipping).

The proposed architecture for the physical machines is shown in Figure 9. This indicates the separation of data between application servers, database servers and backup storage servers.

**Figure 9: Hardware Architecture Diagram**

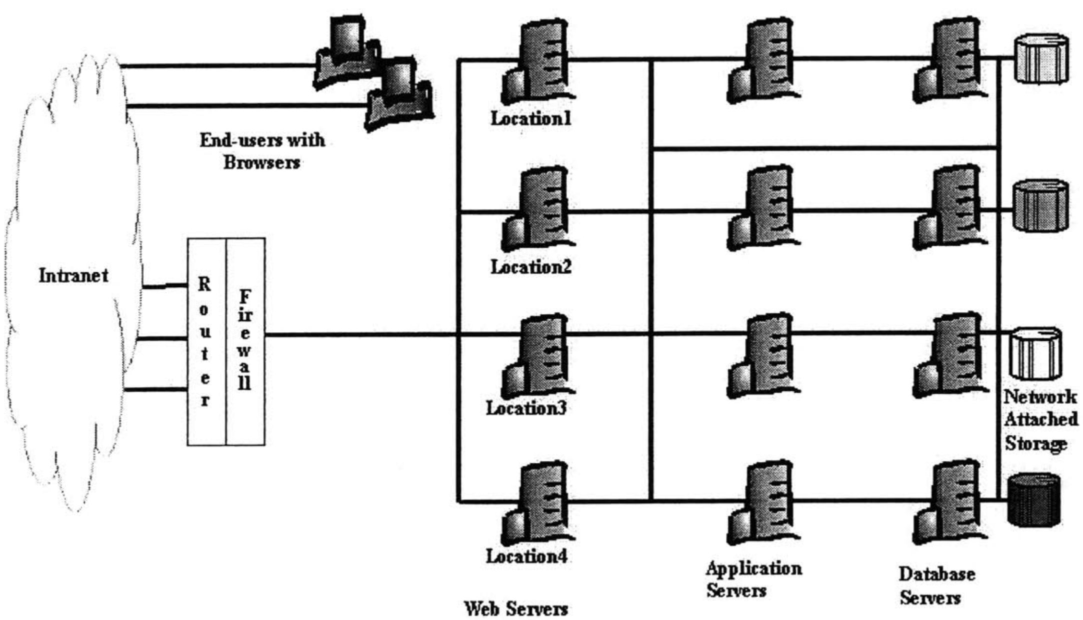



**Figure 10: Modular Architecture of the Proposed IT System**

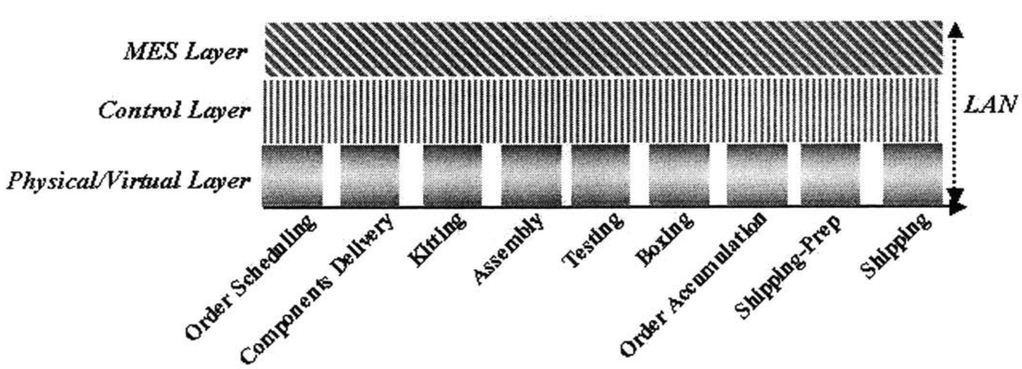


Figure 10 shows the modular architecture that allows seamless communication across the various layers, such that all the processes necessary to run and manage the shop floor are contained within the local area network. This local area network needs to be separated from the corporate intranet. That way, any viruses in the corporate email systems or other failures in the larger network would not affect the shop floor production systems and cause the line to go down.

Other notable changes in the new design are:

1. The current ERP system used to control movement of computers inside the factory should be restricted strictly to the ERP layer. It should be used only as a reporting tool at a higher level. A recent IT initiative (codenamed ODS) can interface with the ERP layer applications and provide data from the legacy system for reporting purposes.

2. The software package that is currently being used at the MES level in the kitting, build and boxing area should be adopted as the MES software for production areas of the factory. The data from this software can be used to make real time decision making for managing the overall factory. This package has its own Web enabled GUI, which can be used to display information for both the operations center and production floor on a real time basis.

3. The reach of this software program should be extended to the distribution and shipping areas. Due to the new factory control layer design, distribution and shipping areas have the capability to use the MES software defined in step 2 above.

4. Splitters should be added to capture data from the scan points in the factory and distribution areas to allow the MES layer software to tap into real time data.

5. The software package used in distribution and shipping areas should be brought into the control layer. That system should be subordinated to the MES layer software. (This will be a cultural change, and will take several months to get approved. Currently, another ERP package is being used in the distribution and shipping areas to control the movement of computers. This software is run centrally and manages

five different factories. This software is not robust and is unreliable. These limitations can be overcome by adopting the recommendations in step 2 and 3.)

6. The data from the various control layer software programs in the kitting area, testing and software download areas, and boxing area should be fed to the MES layer software.

Under this proposed system, all the software in the MES layer and control layer that control each factory reside inside the data center of the same factory. Thus, these layers exist within a dedicated local area network. These software systems can then reliably handle the production volume within a single factory. Based on its design capabilities and its use in other companies, these software systems are estimated to be robust for managing the operations inside the Optiplex factory.

## 4.5 EARLIER ILLUSTRATIONS REVISITED

Section 2.7 of this thesis presents two illustrations of situations where the old management system does not scale effectively in the new Optiplex factory. The new management system developed earlier in this chapter helps address most of the issues described in section 2.7. This section examines how the new system would handle these situations.

### 4.5.1 EXAMPLE 1 – COMMUNICATIONS BETWEEN ASSEMBLY AND DISTRIBUTION AREAS

The example discusses tracking of orders that are held up in the accumulation area when one or two computer systems belonging to that order get delayed in the assembly or test areas. This is a situation where lack of seamless communication between the software in the assembly areas and the distribution areas makes the problem resolution time consuming and tricky.

The new management system proposes that the software programs used in the assembly and the distribution areas communicate with one another seamlessly. They share information on order number, the system identification numbers, customer information etc. in real time at the localized level (the control layer and the MES layer). Additionally, the capability to scan the bar codes on each computer at all stages throughout the process helps the new operations center personnel track all systems belonging to a particular order in real time throughout the factory. They can look up detailed routing and test information on the individual computers as they are being built and can take appropriate action immediately. Thus the new management system greatly improves visibility to systems all through the process.

### 4.5.2 EXAMPLE 2 – CENTRALIZED AND LOCALIZED DECISIONS

This example examines the delays in the pallet build stations caused by misrouting a computer or two in the shipping area of the factory. This decision is managed entirely by the centralized operations center under the old management system. As a result, there is no input to problem resolution at the local level, and this aggravates the situation.

During the redesign, the business processes in the operations center have been decided based on the five criteria generated from the benchmarking effort. Under the new management system, the operations center makes the decision to release an order from accumulation once certain criteria are met. The software programs in the shipping regions determine which pallet build stations are to be used in palletizing this order. The screens available next to each pallet build stations then display pertinent information on the order and the individual computers within that order. As the pallet build operators scan the systems reaching their station, the display is updated to indicate the status of systems. The time available to palletize the entire order is also displayed on the screen. Based on this, the pallet build operators can immediately identify any delays in the process caused by misrouting or mis-scanning. In most situations, the missing systems are routed to the mis-scanned systems lane. Since they have the information on which computers are missing, the operators can track these systems at the misrouted systems lane. If the operators do not find the system in that lane, they can then alert the control center and the control center can determine where the problem happened, and take appropriate actions.

Thus, by empowering these operators, most delays at the pallet build stations can be avoided. This will improve the overall shipping rates at the factory.

## 4.6 SUMMARY

This chapter presents the architecture design of the new management system from the perspective of business processes, facilities and information technology. This new system expands the role of the existing control room to improve coordination between the various components of the order fulfillment process. In other words, this new management system recommends that a centralized operations center be used to make integrated decisions throughout the Optiplex factory. However, this thesis does not recommend shifting all the decision-making to the centralized operations center. There are some decisions that are best managed locally.

Given this dilemma of centralized vs. localized decisions, it is important that this thesis presents some guidelines that can be used to determine which decisions ought to be centralized and which decisions ought to be localized. Five factors identified from the benchmarking effort are used to determine the optimum location for a decision. These criteria are:

1. Business impact,
2. Response time needed,
3. Information input,
4. Decision makers' location, and
5. Decision output.

The decisions (input, decision makers or results) that span multiple process modules typically need tighter coordination between the individual modules. Such decisions are best managed centrally, provided they have a significant business impact and need quick response time.

As noted earlier, Dell factories have been traditionally managed locally by line-of-sight. So, the concept of centralized decisions proposed by this thesis is a cultural change to the way a typical Dell factory is managed. Hence these suggestions can take some time before they are widely accepted. Initially, the management team can analyze the decisions made by the factory against these criteria to decide which decisions need to be centralized and which decisions need to be localized. As and when new issues or problems arise, management has to evaluate them against these criteria. Additionally, when the factory's business needs evolve, these criteria themselves may need modifications over time.

The re-design presented in this chapter defines the business functions handled by each person inside the operations control center. It is important to note that these functions are also subject to changes as the business conditions of the Optiplex factory change over time.

This chapter also defines a new facilities layout for the operations control center at the Optiplex factory. This layout accommodates all the business processes in the factory in the same room, so as to enable quick decision support to problems affecting the line.

On the information technology aspects, this chapter proposes a system-level definition of the IT architecture that will enable collaborative decision making and improve visibility to individual process steps inside the factory.

# 5 FINANCIAL ANALYSIS

## 5.1 CHAPTER OVERVIEW

This chapter presents a financial model to compute the net present value (NPV) of the operations center effort. The model assumes a time horizon of three years. A three-year time period is relevant, as Dell factories are re-built every three or four years. The financial model calculates the net benefits (net of benefits less costs) of the project for three years in future, and uses a hurdle rate to determine its NPV. A weighted average cost of capital of 16.7% is used in discounting the cash flows. Marginal tax rate of Dell is assumed to be 40%.

The benefits of the operations center are presented first, followed by the costs involved. The final section calculates the NPV of the project.

The specific numbers given in the financial model of this thesis are scaled proportionately to indicate the relative importance of various components, while protecting proprietary information.

## 5.2 BENEFITS

The benefits of the Optiplex operations center can be categorized as tangible and intangible.

### 5.2.1 TANGIBLE BENEFITS

Tangible benefits are those that can be easily measured. Five tangible benefits of the operations center are:

1. Supervisor cost reduction,
2. Indirect labor savings,
3. Direct labor savings from productivity gains,
4. Overtime reduction, and
5. Expedites reduction.

**1. Supervisor Cost Reduction:** Supervisor cost reduction arises from better organization and management of the factory. With the operations center, problems affecting the line, rogue or late orders, etc. can be prioritized globally and given to order completion coordinators. The order completion coordinators can now be more efficient as they are dealing with more real time information. This will reduce the number of supervisors that are required at various parts of the assembly area, whose main job is to help identify bottlenecks and solve production problems. This model assumes that the factory can be managed with two-thirds the current number of supervisors. Based on the existing labor rates, this leads to an annual savings of $300,000.

**2. Indirect Labor Savings:** Indirect labor savings come from having fewer full time employees collecting data and reporting the operations metrics daily for production meetings. With the existing capabilities of the control layer hardware and software, it is possible to generate this data automatically. This software can be programmed to generate the metrics and charts that are updated at a desired frequency (one to three minutes) in real time. The individual users in the factory can obtain the current numbers by refreshing their browsers. The annual cost benefits realized from this is around $100,000.

The three remaining tangible benefits are dependent on the productivity improvement achieved by the operations center. As the operations center improves visibility of information across the factory, the factory can make better planning decisions. Better planning can help reduce the amount of overtime that the factory needs in fulfilling the customer demand by the promised dates. It will also reduce the percentage of expedites. (Expedites are those systems that need to be shipped overnight or a similar method, when the customer has only paid for shipping via ground.) Since the amount of productivity improvement is unknown at this stage of the design, sensitivity analysis can be used to quantify these benefits of the project.

However, the project benefits presented in this chapter include only the direct labor savings from productivity improvements. They do not include any overtime reduction and expedite reduction, as these are highly sensitive to the effectiveness of the new operations center. Ignoring these two potential benefits will yield a more conservative estimate of the project's NPV.

Calculations indicate the direct labor savings for a range of quarterly productivity improvements. Direct labor savings do not translate into layoffs. Instead, the idea is to not hire more people as demand increases in future. As Dell is experiencing over 60% annual growth in unit shipments, this will have a big impact.

### 5.2.2 INTANGIBLE BENEFITS

Intangible benefits for the project mainly come from improved data visibility and customer goodwill factor. Improved data visibility in turn has several benefits. Among them the key benefits are:

1. Management time savings,
2. Improved employee morale, and
3. Improved customer satisfaction.

**1. Management Time Savings:** By having accurate data available at their desktops, which can be viewed on their web browsers, managers and engineers do not have to come to the operations center on a periodic basis. When there is an issue or a problem, they can look up relevant data on the intranet, process the information and get an update on the situation from their offices. This can result in significant time-savings.

**2. Improved Employee Morale:** Another benefit to improving data visibility is that it allows the factory to plan more effectively, across all areas. Better planning enables advanced overtime scheduling. This will improve the morale of employees, as they know in advance when they would work overtime and when they would not.

**3. Improved Customer Satisfaction:** The long term effect of the smooth operations of the Optiplex factory is that customers will receive better quality product, delivered to them at the time they have specified earlier. This will improve customer satisfaction over time.

## 5.3 COSTS

The costs of the operations center arise from:

1. Information Technology (IT), and

2. Facilities.

**1. Information Technology (IT):** The IT costs include the cost of developing the systems as well as the annual costs of maintaining and upgrading the hardware and the software. IT groups at Dell have developed and integrated systems based on an architecture that is different from that described by MESA. Also, similar to IT groups in any company, they are being inundated with requests for several projects that they do not have the resources to work on simultaneously. Therefore, the IT planning part of the project has not been completed. As a result, the financial analysis does not explicitly include a set of IT costs for this project. Instead, the analysis first assumes the IT costs to be zero. It then computes the NPV of the project. This NPV is then used to get an idea of the upper bound on IT costs for the project to break-even in the time period used by the model.

**2. Facilities Cost:** The second component of the costs is the cost of facilities. This includes the cost of upgrading the existing control room, knocking down the dry walls and expanding the control room, new ergonomically designed work surfaces, and overhead projectors. These costs are included in the model.

## 5.4 NET PRESENT VALUE (NPV)

In order to compute the net present value (NPV) of the project, net incremental future cash flows (= savings – costs) from the project on a quarterly basis for three years in future are calculated for a range of quarterly productivity improvements (from 0.0% to 1%), assuming the IT costs to be zero. These incremental future cash flows are then discounted using the discount rate of 16.7%. The resulting NPV is as shown in Table 1. The project's NPV ranges from $0.5 million to $7.0 million in the range of productivity improvements considered.

Since the project's IT costs have not been accounted for in this model, it is possible to estimate an upper bound on the IT costs based on the NPV calculations. Assuming a modest productivity improvement of 0.05% due to the operations center, the NPV comes out to $1 million. For this quarterly productivity gain, the IT costs have to be less than $1 million for the project to break even in three years.

**Table 1: NPV as a function of quarterly productivity improvement**

| Quarterly Productivity Improvement (%) | NPV ($ millions) |
|---|---|
| 0.0 | 0.50 |
| 0.05 | 1.00 |
| 0.10 | 1.50 |
| 0.15 | 1.85 |
| 0.20 | 2.25 |
| 0.40 | 3.75 |
| 0.60 | 5.00 |
| 0.80 | 6.00 |
| 1.00 | 7.00 |

## 5.5 SUMMARY

This chapter provides the financial analysis of the new collaborative decision support system. The tangible benefits of the project are identified as supervisor cost reductions, indirect labor savings, direct labor savings, overtime reduction and expedites reduction. While the first two can be calculated easily, the benefits from the last three components resulting from productivity improvements cannot be calculated accurately. This is because the direct labor savings, overtime reduction and expedites reduction depend on the actual productivity gains achieved from the new management system. Hence these components are computed as functions of productivity improvement. Further, the intangible benefits of the project include management time-savings, improved employee morale and better customer satisfaction.

Similarly on the cost side, only the facilities costs can be accurately calculated. The information technology (IT) costs are not evaluated in this model, since that part of the project is yet to be completed.

So the financial model computes the net present value of the project for a time period of three years, as a function of the quarterly productivity improvements achieved through the new management system. For the range of quarterly productivity improvements from 0.0% to 1%, the project NPV is in the range of $0.5 million to $7.0 million. This NPV can be used as an upper bound for the IT costs of the project.

# 6 IMPLEMENTATION AND ORGANIZATIONAL ANALYSIS

## 6.1 CHAPTER OVERVIEW

As the title suggests, this chapter describes the implementation and organizational aspects of the internship. This chapter first gives an update on the implementation aspects of this project. It then presents a description of Dell's organizational aspects that have helped or hindered the project.

## 6.2 IMPLEMENTATION STATUS

The facilities design, presented earlier in this thesis, defines the office furniture, video equipment and projectors required. The project team has worked closely with the internal finance team to develop a budget for the facilities design. The Optiplex management has embraced the facilities design part of the project, and has approved the budget for facilities modifications. At the time of writing, the project team is working with internal and external groups to implement the new facilities design.

The factory management is currently considering the organizational aspects presented in this thesis. So far, it has not made any explicit changes to the organization.

However, the IT part of the project has not moved along as anticipated. Some of the reasons are discussed in sections 5.3 and 6.3 of this thesis.

## 6.3 ORGANIZATIONAL ASPECTS

This section describes the organizational aspects of the company that have facilitated and hindered this project. This factory designed as a first attempt towards virtual integration brings together distribution and shipping functions with order scheduling and computer assembly functions in the same building. Even though these organizations are now physically housed in the same facility, the work functions, cultures, metrics, management approaches etc. used by these groups differ widely. Smooth operation of the factory requires that formal barriers between the organizations, business processes, business performance metrics, information technology systems be broken down. This will enable corporation to achieve its goals of continuing to grow its revenues and profits. This project involves redesigning the management system at this factory to enable smooth communication and information flow between these two organizations.

There are many aspects of the organization that have *facilitated* the acceptance of new ideas proposed by this project.

**Adaptive Culture.** The computer industry is dynamic in nature, with new products and components being introduced frequently. As pointed out earlier, Dell has been at the cutting edge of this fast changing industry, offering new products and technologies to its customers as soon as they become available. This requires that its internal order fulfillment processes adapt constantly to incorporate the new designs and components depending on changes in the industry. In the face of increasing customer demand for computer products, Dell has been adopting newer technologies to make its factories more efficient. This has shaped the organizational culture to be open to change. This culture has helped the Optiplex organization to accept the new ideas proposed by this project.

**Leading Capabilities in Supply Chain Management.** Dell is ahead of its competition in adopting leading practices in supply chain management. It constantly pushes the limits of throughput and cycle time in build-to-order mass customization of computer systems. These capabilities facilitate the company's operations groups to endorse such a novel concept as a collaborative decision support system for streamlining its order fulfillment process. The project reinforces the Optiplex organization's beliefs that it is at the cutting edge of build to order manufacturing and supply chain management.

**Sustainable Competitive Advantage.** The corporation plans to embrace virtual integration to enable its future growth strategy. The Optiplex line of computers makes up more than 40% of the volume of computers that the corporation sells. Thus it is important for the company and for the Optiplex business unit to maintain its competitive advantage by adopting strategies that will improve its efficiency and lower its cost.

There are some aspects of the organizational culture that *hinders* the adoption of the new management system.

**Short-Term Focus.** The corporation is very focused on numbers and meeting its goals quarter after quarter. This makes the management team reluctant to change from a system that helps them meet their objectives in the short term. Thus, in order to facilitate management approval, the project has to appeal to its longer-term goals.

**IT Architecture.** The IT architecture that the corporation uses for managing all aspects of its order fulfillment process has evolved over time. Many of the functionalities have been developed over years, and have become part of the way Dell does business. Even though making changes to this IT architecture to enable virtual integration is inevitable, it will take a more concerted effort than this project. Nonetheless, this project has served as a first step towards such an effort.

## 6.4 SUMMARY

The chapter presents an update on the status of the implementation efforts to date. Optiplex management has approved the facilities design and allocated funds for this. It is currently evaluating the proposed changes in organizational structure to staff the redesigned operations center.

The chapter also discusses the organizational facets of Dell that have facilitated the acceptance of the new management system. The most favorable aspect is Dell's dynamic and adaptive culture, which embraces ideas that enable the company to maintain its leadership position in supply chain management and thus improve its competitive advantage in the computer industry. However, management focus on numbers places an added emphasis on achieving short-term goals. This sometimes poses a higher internal hurdle rate for longer-term projects. Also the IT architecture has evolved so much over the years that it will take a more concerted effort to adapt all the software programs to the needs of the new factory.

# 7 CONCLUSIONS

## 7.1 INTRODUCTION

This thesis presents the work done in developing a new management and decision support system at a computer manufacturing facility at Dell Computer Corporation.

## 7.2 KEY FINDINGS

In the increasingly competitive computer industry, Dell Computer Corporation's future growth strategy calls for virtual integration – i.e. real time integration of information flow between the various functions in the value chain internally, and between the company, its suppliers and its customers externally. Dell's newest computer factory designed to build its corporate desktop line of computers is a first step in virtual integration in its order fulfillment process. This factory incorporates all elements in Dell's order fulfillment from order scheduling and computer assembly to distribution and shipping. Dell begins to manage this factory with a hybrid of traditional line-of-sight management and centralized management via a control center.

The thesis identifies that this hybrid management approach does not scale effectively due to differences in business performance metrics, management styles, and lack of data and information flows across the various functions. Additionally, the two organizations – the computer assembly functions, and the distribution and shipping functions – have not worked so closely with one another in the past.

This new factory has been designed such that there is tight interdependence between the tasks performed by various functions. Literature identifies that whenever such high dependencies exist between the various components of a process, management decisions should be coordinated across all the components. However, in this Dell factory, decisions are not highly coordinated. The components of the factory are managed as though they are independent. This often leads to local optimization as opposed to global maximization.

The new factory designed as a first step towards virtual integration presents the following challenges:

1. Lack of consistent metrics used throughout the factory makes it difficult to prioritize decisions across the entire factory;

2. Lack of coordination between centralized and localized decision-making introduces delays in the order fulfillment process;

3. Centralized architecture and rigid information exchange definitions of many software packages hamper seamless information sharing between the various IT systems; and

4. Different background and work cultures of the assembly and distribution areas impede coordinated decision-making.

In order for this factory to reach its throughput and productivity targets, the factory management decisions need to overcome the above challenges by collaborating across all the key elements of the supply chain. Only then will the factory be able to move towards its goals of achieving a customer centric view of order fulfillment.

This thesis proposes to develop such a collaborative management system so as to coordinate decision-making across all functions represented in the new factory. In this high velocity manufacturing facility, coordinated decisions can be made only in a centralized location, where decision makers knowledgeable about all aspects of the factory can quickly identify and solve problems as and when they occur.

This idea of centralized decision-making is rather innovative in a computer-manufacturing environment. In order to learn best practices from other industries, the thesis benchmarks control centers in other manufacturing and service industries along three areas – business processes, facilities and information technology architecture.

As a result of the benchmarking effort, five criteria emerge to determine whether a decision is best managed centrally or locally. These five criteria are:

1. Business impact,

2. Response time,

3. Information input,

4. Location of decision makers, and
5. Decision output.

For any decision to be centralized the first two criteria have to be met; i.e. the decisions and the business processes managed in the operations center should have a high impact on the factory performance and require quick response. If not attended to, then these problems can escalate and affect the performance of the factory. Thus, decisions that need to be in the operations center should have a huge business impact and require rapid response. In addition, decisions that are centralized have to meet at least one of the other three criteria. Information coming from different sources can be consolidated in the centralized operations center. Decisions that span multiple areas of the factory can be made more optimally in a centralized location. Finally, when the results of the decisions need collaboration with a wide range of areas within the factory, such decisions can also be best made centrally. To summarize, the decisions (input, decision makers or results) that span multiple process modules need tighter coordination between the individual modules, and are best managed centrally, provided they have a significant business impact and need quick response time.

All companies visited in the benchmarking effort use dedicated hardware that is locally resident at the facilities and use a dedicated network to manage their control center operations. Some companies take a simplistic approach and house only the functions necessary for collaborative decision making inside the control room, where as others house all the personnel involved in controlling its operations inside the control room. Either way, the roles of the personnel inside the control room are clearly defined and so is the organizational hierarchy.

These key lessons from the benchmarking effort are used in re-designing the Dell factory's operations control center.

This thesis specifies the business functions handled by each person inside the Optiplex operations control center. It is important to note that these functions are subject to changes as the business conditions of the factory evolve over time.

The thesis defines a new facilities layout for the Optiplex operations control center. This layout accommodates all the business processes in the factory inside the operations center, so as to enable quick decision support to problems affecting the line.

On the information technology aspects, the thesis proposes a system-level definition of the IT architecture that will enable collaborative decision making and improve visibility to individual process steps inside the factory.

The thesis also presents the business case for this re-design effort by calculating the net present value (NPV) of the net benefits (benefits less costs). The tangible benefits of the project are identified as supervisor cost reductions, indirect labor savings, direct labor savings, overtime reduction and expedites reduction. While the first two can be calculated easily, the benefits from the last three components resulting from improvements in productivity cannot be calculated as accurately. This is because the direct labor savings, overtime reduction and expedites reduction depend on the actual productivity gains achieved from the new management system. Hence these components are computed as functions of quarterly productivity improvement. Similarly on the cost side, the model includes only the facilities costs. The information technology (IT) costs are not evaluated since that part of the project is yet to be completed. To summarize, the financial model computes the project's NPV as a function of the quarterly productivity improvements achieved through the new management system. The project NPV ranges from $0.5 million to $7.0 million for the range of quarterly productivity improvements from 0.0% to 1.0%. This NPV then serves as an upper bound for the IT costs for the project to break even.

The thesis finally discusses the organizational facets of Dell that facilitated the acceptance of the new management system. The most favorable aspect is Dell's dynamic and adaptive culture, which embraces ideas that will enable the company to maintain its leadership position in supply chain management and improve its competitive advantage in the computer industry. However, management's focus on numbers places an added emphasis on short-term goals. This sometimes poses a higher hurdle rate for longer-term projects.

The IT systems at Dell have evolved around a centralized architecture that is not conducive to exchanging information seamlessly between various process steps. It will take a more concerted effort to adapt the IT architecture to the needs of the new factory.

The management's acceptance of the key findings of this project suggests that Dell wants to continue to be at the cutting edge of supply chain management and offer its customers the best and the latest technologies at a competitive price point. With this willingness to embrace change and focus on meeting its customer goals, Dell is well poised to become the number one computer systems company in the world.

## 7.3 AREAS FOR FURTHER STUDY

This thesis describes the criteria used for identifying whether a decision ought to be centralized or localized. An area for future study will be to use these criteria in developing a dynamic rules-based system that can be used to determine which decisions are centralized or localized. This can be further developed into a dynamic decision support program that can take as inputs the conditions in a factory and then produce as output the appropriate response based on past decisions and current factory business conditions. When faced with a new situation or problem, this approach might break down. To handle such conditions, a dynamic simulator can be developed to propose solutions to new situations based on pertinent data, heuristics and factory business conditions as inputs. These tools can be used to improve the consistency and efficiency of the decision-making process in this high volume computer manufacturing facility.

Another area for future study involves developing the information technology architecture defined at a system level in this thesis. Many of the IT systems used currently have evolved over time. As the demand has grown considerably over the years, many existing software systems have reached their peak capability, or are unable to optimally support the order fulfillment process. One can start with the high-level system design specified in this thesis, and develop capabilities of these systems to further optimize the overall decision-making process.

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