Multi-Site Inventory Balancing in an Extended Global Supply Chain

By
Amy M. Reyner
B.S. Industrial Engineering, New Mexico State University (1999)

Submitted to the Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Mechanical Engineering

In Conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2006

Signature of Author ____________________________
Sloan School of Management
Department of Mechanical Engineering
May 12, 2006

Certified by____________________________
Jonathan L.S. Byrnes, Thesis Supervisor
Senior Lecturer, MIT

Certified by____________________________
David E. Hardt, Thesis Reader
Professor of Mechanical Engineering

Certified by____________________________
Jeremie Gallien, Thesis Supervisor
Associate Professor of Management Science

Accepted by ____________________________
Lallit Anand, Chairman, Committee on Graduate Students
Department of Mechanical Engineering

Accepted by ____________________________
Debbie Berechman, Executive Director of Masters Program
Sloan School of Management

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Abstract

Dell is a well-known consumer electronics manufacturer that has experienced astounding rates of revenue growth since its inception in 1984. Regarded as a supply chain innovator, Dell has attained success through industry-revolutionizing ideas such as vendor-managed inventory, pull manufacturing, and direct sales. Today, continuance of revenue growth for Dell requires not only rapid innovation, but also rapid geographic and product expansion.

Until a few years ago, Dell only had one facility in the United States. All of Dell's US-based systems and processes were constructed to optimize this single factory. Since 1999, Dell has added a number of new facilities in the US – factories and merge centers – for the sake of proximity to customers as well as additional capacity. Also, Dell recently began practicing more product leveling than in the past, producing multiple types of systems at the same factory. Finally, Dell's US supply base has migrated to Asia, as have those of most in the industry. This confluence of complexities has led to a significant increase in instances of material imbalances, whereby any given part has not been distributed to the various sites in accordance with their proportion of actual demand, often resulting in costly expedites from site to site or delayed shipments to customers.

Part of the solution to this problem is what Dell has termed "Dynamic Replenishment". As Dell's US supply has shifted from America-based to Asia-based over the past five years, the effective lead time for most ocean-shipped parts has increased from days to several weeks. As a result, the site-level forecast for routing of an ocean shipment is more frequently incorrect by the time it reaches the US, and material imbalances occur. In order to reduce these imbalances, Dynamic Replenishment processes aim to proactively re-route material (if needed, based on campus inventories and forecasts) upon arrival at the US port. This thesis will focus on the tools, information, processes, and organizational roles that are required to ensure proper routing of material at the latest possible juncture in Dell's ocean-network supply chain. Treatment will also be given to the idea that the material balancing problem is one of many that result from Dell's rapid supply chain growth, and some related issues will be examined from this broader perspective. (*A note on scope*: The content of this thesis is related only to Dell's *US-based* operations. All history, facts, and comments should be taken in this regard.)

Thesis Supervisor: Jeremie Gallien
Title: Associate Professor of Management Science

Thesis Supervisor: Jonathan L.S. Byrnes
Title: Senior Lecturer, MIT

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Acknowledgements

I would like to thank the following people for their support of this thesis as well as of my entire LFM experience...

Dell's Manufacturing and Supply Chain management, who openly welcomed new ideas and have offered steadfast support to the LFM program for many years,

my Dell project supervisors – Matt Snyder and Shayne Myhand – for their support of the project as well as of my own personal learning and development,

Julie Summers, my project counterpart without whom the project would not have achieved the success it did, and who became a good friend along the way,

my MIT thesis advisors – Jonathan Byrnes and Jeremie Gallien – for providing key insights throughout the project and valuable input to this thesis,

Intel Corporation, for its support of my advanced education, and those at Intel who have supported me personally throughout my career,

The LFM Program and Staff, who work so hard each year to offer this amazing opportunity to students like myself,

my friends in LFM, from whom I have learned as much as I did in two years of classes,

and my family, who are the reason that I found my way here.

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1 Dell and Industry Overview

1.1 Dell's Early Success

The story of Dell's beginning is a reasonably common one. It is the story of a driven man with superb market timing. The story of Dell's survival, however, is not so simple; it is nothing short of a tale of revolution in business and supply chains. Dell's past and its pinnacles of success have defined not only what the company is today, but what the *industry* is as well. Therefore, I offer a requisite brief history of the company and a summary of its defining strategies.

Before Dell emerged, IBM was the only major PC producer, and consumers were so under-informed that profit margins could be as high as 80% (8). Post-sale service was non-existent and not considered an important element of a computer sale. Suppliers of key components such as processors and operating systems were still working to develop mature products and to find a market large enough to establish the power that they knew they could someday obtain. In this ripe atmosphere Michael Dell started his PC company out of a college dorm room, and moved within one year to a 30,000 sq. foot building to support the booming business (8).

It would not be long before the environment became more challenging. Many saw the opportunity that Dell did, and names such as Compaq, Gateway, and Macintosh joined America's household vocabulary along with IBM and Dell. In addition, IBM's unintended gift of sizeable market power to Intel and Microsoft further complicated the position of computer manufacturers. It became a game of survival for these companies, but Michael Dell did not want to survive. He wanted to win. He accomplished this through one revolutionary idea and remarkable follow-through on the success it fostered.

That revolutionary idea is one that may not sound so revolutionary today: Listen to the customer. Throughout the birth of the personal computing industry, there was a pervasive attitude that computer engineers should determine what customers need and they will purchase it; a "build it and they will come" type of strategy. Dell realized, in part because he did not have the capital to invest in anything the customer didn't want, that "it always made more sense [...] to build a business based on what people *really* wanted, rather than guess at what we thought they might want" (8). This marked the beginning of a practice that is widely copied in business today and a phrase that has become commonplace in the business world: The Direct Model.

Dell's "Direct Model" is often regarded as its explicit use of the internet to sell directly to customers, but it is much more than that. Application of a direct model only *begins* with selling directly to customers. It is made complete by retaining immediate knowledge of those direct sales and using it to design a better product, understand future needs of the customer, customize sales to specific types of customers, and to establish a more informed supply chain, among other practices. While competitors could only guess at what was being sold through their retailers, Dell was reacting immediately to shifts in customer needs and communicating customer demand throughout their supply chain with little or no delay. This is the advantage that initially drove Dell to the top, but the company has devised a number of innovative strategies in addition to this one in order to stay on top and continue climbing.

1.2 Dell's Strategies

Dell's primary strategies are clearly outlined in a diagram available through its public website (1):

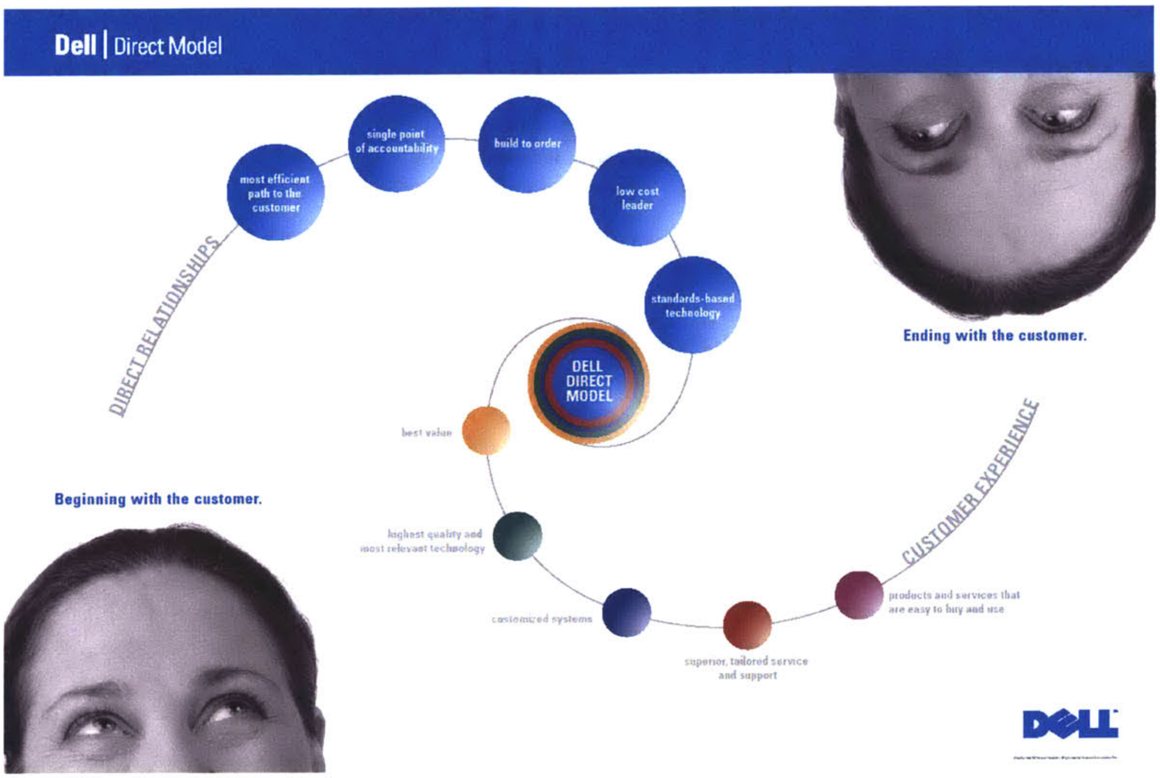


Figure 1. The Dell Direct Model (1).

The foundations of this model are direct relationships with their customers and maintaining a positive customer experience once those relationships are established. They achieve this through strategies such as build-to-order manufacturing, low costs, customization, and clear and simple service, among others. The company has been highly successful with these strategies for the past 20 years, but the past year has introduced difficulty in maintaining the sky-high growth levels with which Dell's investors have become so enamored.

Dell announced recently that its next major goal is to achieve \$80 billion in revenues in approximately three years (6). This will be no small feat. At first glance, a jump to \$80 billion in three years appears to be in line with historical revenue trends (see Figure 2).

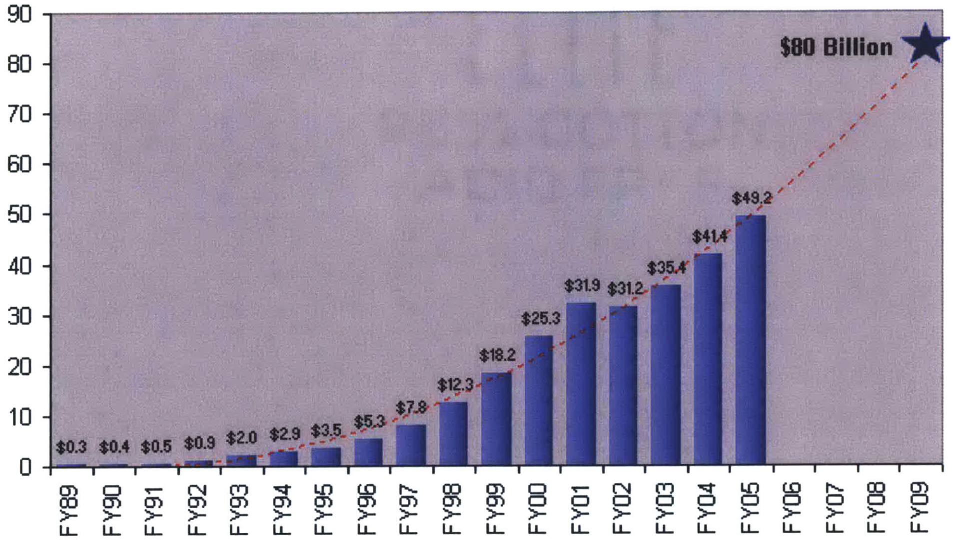


Figure 2. Dell historical and projected revenue. (10)

However, one must take a glance at the current list of $80+ billion companies to understand what it takes to reach this goal. First, take note that in 2005, out of 2000 companies reviewed by Forbes, only 25 have revenues at or above $80 billion, with the numbers tapering sharply above $55 billion (see Figure 3).

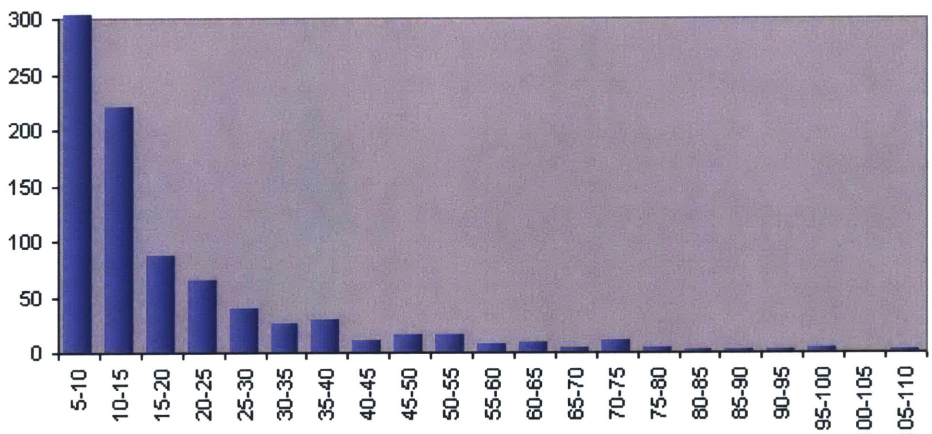


Figure 3. Distribution of companies at incremental annual revenue levels. (11)

Also, most of these companies are either based in the consumer durables, oil & gas, or insurance markets, or are large conglomerates, in total accounting for 72% of all companies with revenue above $80 billion in Forbes' study (see Figure 4).

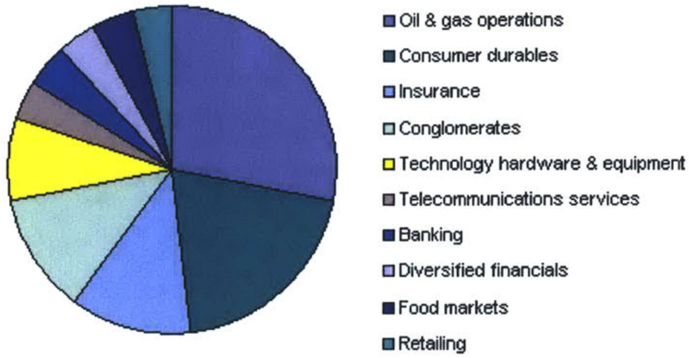


Figure 4. Number of Forbes 2000 companies, by industry, with revenues above $80 billion. (11)

Although we see that two technology companies have ventured into the $80 billion+ realm, this accounts for only 8% of all companies which have accomplished the same. The point: it is not common or easy for a technology company to achieve the scale and product portfolio needed to bring in $80 billion in annual revenues. Dell is well aware of this, and is tackling the challenge on multiple fronts.

Steps to drive toward the $80 billion goal range from global expansion to a widening of the product portfolio. Dell's primary markets now include the US, Europe, Asia, and Latin America, while their product portfolio has expanded from just PCs to servers, storage, workstations, networking, notebooks, PCs, printers, software, and various related services (see Figure 5).

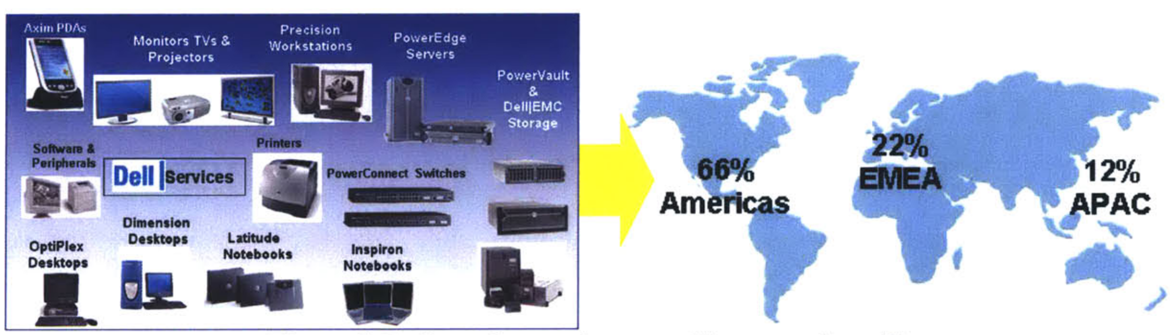


Figure 5. Dell product and geographic expansion. (9)

Dell's $80 billion mission and related strategies are driven by a low-margin industry that demands ever-increasing market share for survival. Following is a brief review of the PC and consumer electronics industry and some of Dell's most prominent competition.

1.3 Industry Overview

In the beginning, sometime around the early 1980's, all a computer manufacturing company had to do to succeed was keep costs down and install the next generation microprocessor before the competitors did. Processing power was the limiting factor to virtually all computational functions, and customers were hungry for more. In addition, focus was primarily on the US market, as most customers were still located in this region and it was also the region that led adoption of newer technologies (especially because most of those technologies were developed in the US). Strategies for success were clear and a plethora of competitors soon entered the market.

IBM was the first major entrant to the consumer PC market. It was highly successful during its early years as customers discovered the potential of the PC. However, the success did not last long as Intel and Microsoft eventually narrowed IBM's margins through their increased control of the most critical computer components. The computer market quickly shifted from a strategy of vertical integration and high technology to one of outsourcing and low cost. As this transition occurred, competitors such as Dell, HP, and Compaq entered the market. The mid-eighties through early nineties would be a challenging time for these manufacturers as they fought for market share amidst intense price competition.

Today, each competitor in the PC market has devised a particular strategy to help it succeed in this somewhat unappealing market. For example, IBM established a key focus on large customers and providing comprehensive service to those customers throughout the lifetime of their products. IBM has gone as far as to establish an all-out consulting division for its large customers, and has sold its consumer PC business to Lenovo in order to focus on such endeavors. Hewlett-Packard's strategies involve heavy investment in research of new technologies and expansion into computer-related markets, such as printing.

What can be said about the strategies of all companies in this industry is that every one must take into account a rapidly evolving industry as well as one that is expanding globally at staggering rates. Nearly every company that at one time focused on PC manufacturing is now dabbling in associated electronics such as printers, handhelds, and even televisions. In addition, extended services have become a non-negotiable element of computer and related sales. Geographically, there is a dynamic battle playing out for markets such as China, Latin America, and Europe. Most of these markets are not yet mature and the struggle for new market share in a low-margin, relationship-based industry is intense. Finally, supply bases for computer manufacturers have dispersed themselves around the globe as suppliers are forced to seek lower labor rates in a low-cost industry.

Challenges such as these have wreaked havoc on the businesses and supply chains of today's key industry players, which include Dell (18% world market share of PC shipments), HP (16%), Lenovo (6%), Acer (5%), and Fujitsu/Siemens (4%) (7). SKU count is exploding as new products are introduced and people, IT systems, and suppliers struggle to keep up. Communications are becoming more and more difficult as organizations expand globally and frequent re-organizations are required to keep up with evolving markets. Supply lead times have jumped from days to weeks as suppliers move to various countries throughout Asia. These issues have presented major hurdles for Dell, in particular, due to their high-volume make-to-order business.

Following is a review of the evolution of Dell's supply chain and a study of how these challenges affect Dell's supply chain today.

2. The Dell Supply Chain

2.1 World-Class Supply Chain Design

In 1984, Dell's supply chain consisted of a dorm room at UT Austin and a few nearby component suppliers. Ten years later, Dell was bringing in nearly $3 billion in annual revenues. One might speculate, then, that Dell's supply chain must have evolved in significant ways to accommodate this growth, but in many ways the supply chain in 1994 was nearly identical to that of 1984. While it had expanded to new suppliers, new customers, and new products, the essential *design* remained the same. In the US, Dell manufactured in one location: Austin, Texas. It manufactured all products there and shipped to all customers from there, and many suppliers were still located in nearby Texas cities.

Dell's supply chain was run in this manner for many years, until the early 1990's when key changes began to evolve in the supply chain framework that Dell had built. One key change began with the team that managed Dell's hard drive supply. This team worked with a number of suppliers who had established a network of third-party warehouses throughout Austin to accommodate Dell's ramping production. The buyers on the hard drive team established a daily protocol of calling the warehouses, documenting each one's level of inventory, and issuing "picks" from particular warehouses as needed. This simple procedure eventually became Dell's renowned policy of utilizing what they call "SLCs", or "Supplier Logistics Centers". In light of this success, more and more suppliers were asked to place their inventories in third-party warehouses and convey inventory levels to Dell on a regular basis so that inventory could be well-managed.

A large part of the reason that Dell was able to accomplish such improvements was because it had become such a large percentage of its suppliers' business. As Dell grew extremely rapidly throughout the late 1980's and early 1990's, it maintained a supplier base near its facility in Austin, Texas. These smaller local suppliers faced the nearly inevitable fate that they would become largely dependent on Dell's booming business (with the exception of larger suppliers such as Intel and Microsoft). As Dell's buyer power grew, it keenly recognized the potential to leverage that power in order to establish a supply chain advantage and maximize cash flows. During that time (primarily throughout the 1990's), Dell implemented a number of new initiatives that established supply chain design as a key strategic advantage for the company. The following is a summary of the most well-known supply chain strategies that Dell has very successfully developed and employed since that time.

> SLCs (Supplier Logistics Centers): The majority of Dell's vendors are required to store an agreed-upon amount of inventory in third-party logistics centers that are generally located within walking distance of the factories they supply.
>
> VMI (Vendor-Managed Inventory): This element has two essential components. The first is the fact that a supplier is considered to be responsible for understanding Dell's forecasted demand at all locations and maintaining a set level of buffer stock (in the SLCs) in order to meet that demand at a given service level. Dell communicates this forecast on a weekly basis and suppliers are expected to accordingly modify production

and shipment schedules without specific direction from Dell. The second component of VMI is the idea that a supplier owns its inventory until it is *inside Dell's factory*. This is critical, as it removes a major portion of Dell's inventory from its books, and also eliminates a significant portion of Dell's obsolescence risk, which is a major concern in the consumer electronics industry.

Pull Manufacturing: Dell's "Direct Model" allows it to track customer demand to the hour, which enables it to maintain only *exactly* the supply it needs, at any given time, in its factories for production. Dell takes advantage of this by adhering to a strict pull manufacturing system, whereby supply is pulled from the SLCs every two hours in quantities that are just enough to satisfy demand for those two hours (See Figure 6). This minimizes inventory levels, streamlines production, and forces more accurate accounting of supply. In recent industry terms, it makes Dell's factory "lean".

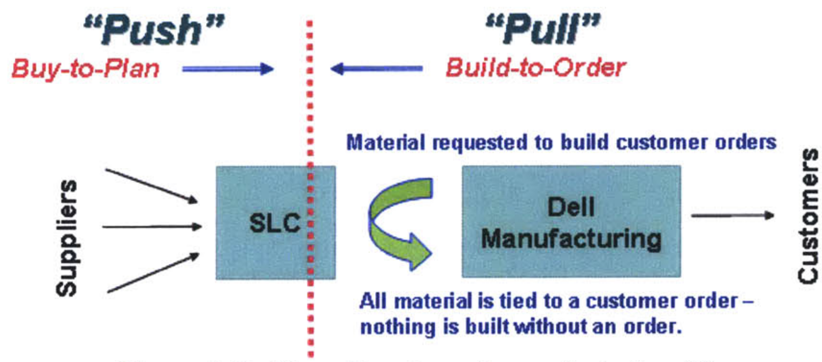


Figure 6. Dell's pull system of manufacturing (9).

Cash Conversion Cycle Management: Dell's amazing *negative* 36-day cash cycle is one aspect of their supply chain that is not always discussed in tales of their excellence, but it is a critical component of their success. Most computer manufacturers pay suppliers about 30 days before a computer is shipped, bought by a customer, and paid for by that customer (3). Dell, on the other hand, collects customer payment *immediately* through internet sales, and does not disburse cash for supplies for those purchases until a few hours before the computer is made and shipped (due to VMI and pull production policies). As a result, Dell's customers and suppliers essentially finance its operations.

The combination of these and other elements has placed Dell on a veritable throne over the kingdom of supply chain design. Whereas twelve years ago Dell maintained 20 to 25 days of inventory in a network of warehouses, today it has no warehouses and only two hours of inventory in its factories. It accomplishes all of this while continuing to produce more than 80,000 computers each day. It must be noted, however, that Dell's supply chain faces many of the same challenges as its competitors in spite of its ingenious design. Ever more demanding consumers have driven the expansion of both manufacturing locations as well as product portfolio. An unforgiving low-margin industry has forced Dell's supply base to move to the other side of the world in search of lower labor costs. Demands such as these have intensified at staggering rates over the past five years, driving geographic and product-based evolutions for Dell that push even the limits of its superior supply chain.

2.2 Dell's Supply Chain in the 2000's: Evolution and Expansion

In reviewing Dell's supply chain history, one might say that 1998 marked the beginning of a major supply chain transition that took place on multiple fronts.

SLC Implementation

First, 1999 brought the introduction of a full-blown SLC strategy. Third party logistics providers and warehouses were consolidated and suppliers were now required to use the SLCs that Dell had arranged. The SLC and VMI policies became more explicit, and processes and IT systems evolved to accommodate this.

Addition of Nashville and North Carolina Facilities

In 2000, Dell realized it needed more capacity and questioned whether that capacity should be located in Austin. A strong argument was made for the benefits of collocation with Dell's customer base in the East (faster delivery times, hence improved customer service), and for reduced outbound logistics cost as an additional benefit. Consequently, a new factory was constructed in Nashville, Tennessee, originally chartered to build only consumer PCs, while Austin would continue to manufacture PCs, workstations, and servers. More recently, a new factory in Winston-Salem, North Carolina was also constructed.

"GeoManufacturing"

As Dell's logistics and manufacturing teams continued to seek further cost reductions, they came to the realization that they could achieve higher capacity utilizations, mitigate risk, and further reduce distance to the customer by implementing a product leveling strategy across their two factories. A policy called "GeoManufacturing" was implemented whereby both factories would produce PCs and Workstations, with quantities determined by an anticipated distribution of customer locations (called a "Geo Split").

Introduction of Merge Centers

In an effort to continue optimizing their geographic footprint, improve customer service, and better focus the resources of their manufacturing facilities, Dell began to introduce "merge centers". These merge centers would either merge a system (PC, workstation, or server) with its corresponding monitor, software, and peripherals, or merge a bundle of non-system items (eg. an order for a mouse and a keyboard) before shipment to the customer. The addition of this step in Dell's process allowed them to 1) further reduce distance to the customer, 2) eliminate a portion of inbound logistics costs by locating merge centers closer to ports on the West Coast, 3) allow factories to focus on manufacturing and leave packaging operations to others, and 4) improve customer service by packaging items together for one single delivery. Over time, merge centers were introduced in Nevada, Ohio, Texas, and Tennessee.

Migration of US Supply Base to Asia

The migration of a US supply base to primarily Asian countries is not a challenge that Dell faced alone. Most consumer electronics manufacturers have had to deal with this issue in the past five to ten years. This migration took place at an astounding pace as suppliers fought to stay alive in commodity electronics markets. The following chart depicts the pace at which the US supply base for a key component, chassis, migrated from the US to Asia for Dell.

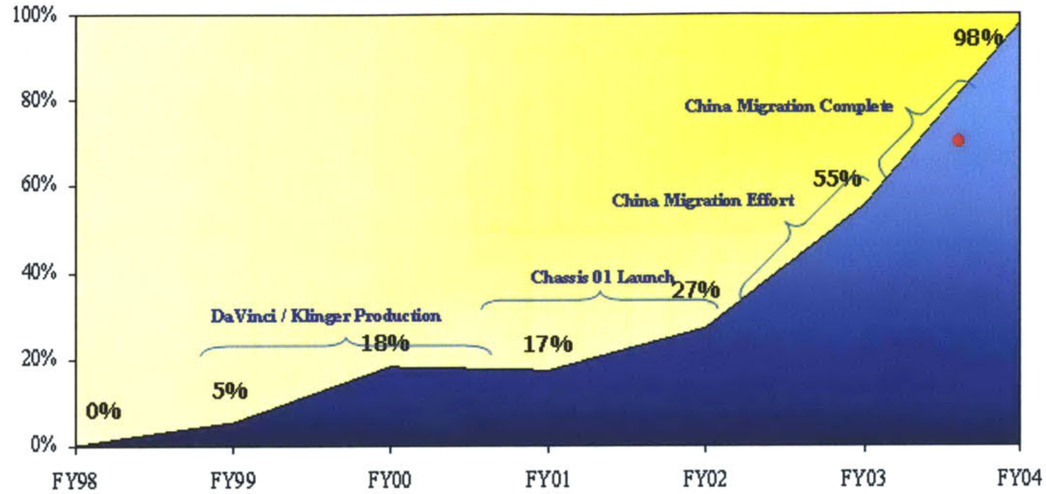


Figure 7. Rate of migration of chassis suppliers to China from FY 1998 to FY 2004. (9)

Expanding Product Portfolio and Complexity
In efforts to reach its $80 billion goal, Dell has introduced a slew of new products to its portfolio, and has added new levels of complexity to these products. An online customer of Dell would have, five years ago, most likely logged on to find a focused advertisement of the latest, most powerful PC or notebook available. Today, however, that customer will be inundated with ads for a PC, the latest flat-screen televisions, and a high-resolution monitor, with options to explore MP3 players, handhelds, printers, and gaming systems (see Figure 8). These additions represent Dell's effort to fully leverage its competitive advantages in marketing, supply chain, and other areas to achieve maximum market share.

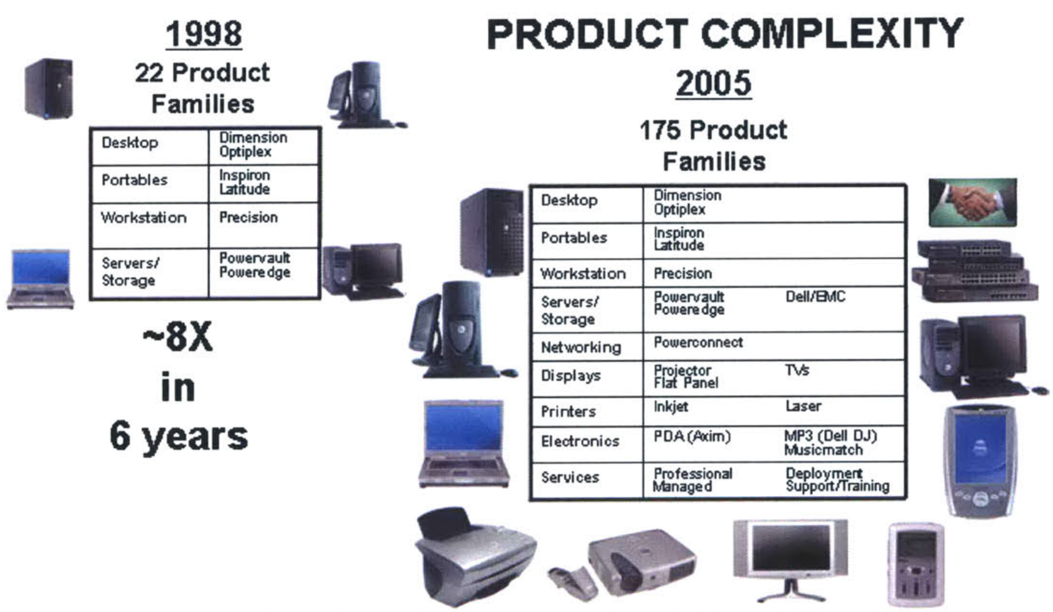


Figure 8. Dell's product expansion from 1998 to 2005. (9)

It is important to keep in mind that the changes discussed above have taken place, for the most part, in *only five years*. Dell, as always, has done an amazing job of keeping up with these changes and continuing to hand in ever-higher revenue report cards to Wall Street. However, there are some undeniable complications that have arisen in Dell's supply chain as a result of these changes, and the challenges must be faced head-on if Dell is to remain competitive. A review of some of these challenges is offered in the following section, particularly those that essentially drove the need for the analysis and improvements to be reviewed in this document.

2.3 Today's Supply Chain Challenges

Having reviewed six major supply chain transitions in the previous sections, one might expect to see a broad discussion of varied impacts that they have on Dell's supply chain. I assert, however, that a significant portion of the impact of these transitions can be summarized in only *two* challenges for Dell's supply chain (without respect to organizational challenges to be addressed in a later section). Those challenges are an *increase in supply lead time* and the *disaggregation of supply and forecasts*. The following offers a brief review of the impacts of these effects on a supply chain.

Inventory and Service Levels

All conclusions in this section are derived from the relationships between lead times, demand variation, and inventory levels. The following defined relationship will look familiar to those with the most basic of operations backgrounds:

$$s = x_L + k\sigma_L \text{ (Formula 1),}$$

where s is a reorder point, x_L is the amount of stock necessary to supply average demand for the duration of the supply lead time, k is a factor based on the desired service level, and σ_L is the variation of demand over the supply lead time.

We can say, given this relationship, that

> 1) when lead time increases, either inventory levels must increase to maintain the same service level or the service level must decrease and
>
> 2) the same is true for an increase in demand variation.

Each supply chain challenge that Dell faces, as outlined above, can be categorized as causing one of these two effects.

1) Increases in Supply Lead Time

The migration of Dell's US supply base to Asia is listed above as one of six major supply chain transitions, but it deserves recognition as possibly the most challenging obstacle to overcome in the next decade. This is no minor increase in lead times. Dell has gone from what were lead times measured in days for local suppliers to lead times measured in weeks (typically four to six weeks) for those in Asia. For unconstrained parts (those whose collective industry supply exceeds collective demand), this means a need for significantly higher inventory levels. For parts that are industry constrained, this can mean severe shortages in supply.

2) Disaggregation of Demand

It is documented that, as demand is disaggregated, its overall variation increases. Specifically, the amount of inventory required to maintain the same service level (as in the case of no disaggregation) increases at a rate equal to the square root of the number of "divisions" in demand that are introduced, given certain basic assumptions. The disaggregation of demand can occur in multiple ways. For Dell, as mentioned previously, it has occurred on two primary fronts. First, each new factory, although addressing some new portion of new demand, disaggregates current demand for desktop orders *geographically*. It is important to note, in this case, that the significance of the effect that this geographic disaggregation has on Dell is dependent upon at what point in the supply chain supply is routed to a particular location. If supply could be routed to a single location, and only dispersed to each factory at the last minute, the effects of geographic disaggregation would be minimal as there would exist little time for demand variance to have a large effect. However, if there is a lag between the disaggregation (or routing to a particular location) and actual customer purchase, then significant levels of variance in demand are likely to occur and higher inventory levels must be maintained in order to meet the same service levels. The second type of disaggregation that Dell faces is the policy of GeoManufacturing, which disaggregates *products* (specifically desktops and workstations). The demand pooling effects accomplished by serving one type of product out of one single location are lost as product production is dispersed across multiple factories. In addition, product demand disaggregation is amplified by Dell's addition of new products to its portfolio. This spreads demand over more products (most likely with less demand per product), resulting in less predictable product demand levels.

Dell and many other industries are already seeing the effects of the challenges of increased lead times and demand disaggregation. A recent Annual State of Logistics Report (published by the Council of Supply Chain Management Professionals) stated that "As global supply chains have become longer and less predictable, companies have been carrying higher-than-ideal levels of inventory... prudent managers want to minimize inventory, but if they do that, they could be left with empty shelves." (5) Many speculations exist regarding Dell, specifically, as well. *Logistics* magazine states that Dell increased its days of inventory from three to four in FY 2005, and comments that "it may signal that the logistics icon is stretching its supply chain as it grows across product lines and geographic borders." (4) Goldman Sachs & Co. adds that Dell's "increased size, larger international exposure, and much broader product line have reduced its nimbleness." (6) These analysts and many others will be watching carefully to learn how Dell and a number of other companies leap over such supply chain hurdles.

Having reviewed the extremely rapid evolution of complexity in Dell's supply chain and products, one would be remiss not to offer a complementary view of the impact on supply chain information systems, which are becoming an ever-more critical component of supply chain success. Following is a brief note on Dell's efforts and difficulties in maintaining alignment between its IT systems and an increasingly complex supply chain.

2.4 Note on Supply Chain IT Systems

In today's highly competitive environments, real-time information sharing and data analysis are critical components of a successful supply chain. Dell recognizes this, and has taken many steps to remain on the leading edge. Brian Fugate and John Mentzer offer a glowing review of Dell's success in developing supply chain IT systems:

> "The company uses information technology to gather and share a constant stream of data on supply and demand trends. On the supply side, Dell gathers real-time information about the inventory levels of its suppliers at various positions in the supply chain. The suppliers are also expected to share information such as capacity outlooks and new technology drivers. In return, Dell provides direct signals of customer demand to suppliers and shares current and projected market shifts and sourcing strategies. At the same time, the company's extranet-its dedicated Internet link with outside partners-enhances collaboration on, and commitment to, forecasts. This visibility up and down the supply chain allows Dell to manage demand in real time." (2)

Indeed, Dell has taken a lead in leveraging partnerships and information sharing throughout their supply chain. However, the connections are not always as seamless as they are often portrayed. One manager at Dell stated that, in some ways, Dell has been a victim of its own success. In other words, Dell has grown so quickly that it can't keep up with the growth in some aspects of the business. Information technology is certainly one of those aspects. Although Dell has developed and purchased a number of real-time applications for supply chain collaboration, they are many, varied, and sometimes unreliable as small or externally-developed applications struggle to handle increasing volumes of information. In addition, much of the information in these applications is heavily dependent on numerous email exchanges and Microsoft Excel analyses. These factors present many challenges in the everyday compilation and utilization of data at Dell, and improvements in this regard will likely provide productivity and efficiency gains across the organization.

IT systems were only one of the many challenges that Dell's supply chain organization faced, and over the past five years the technical challenges as described in this section have been accompanied by similar growth in organizational complexity. The following section offers a review of this organizational evolution.

2.5 Supply Chain Organization Evolution and Challenges

In 1998, the year that I have referenced as the beginning of a supply chain metamorphosis for Dell, Dell's supply chain organization was fairly simple and was designed for efficiency in working with local suppliers. (Note that, in this discussion, a treatment is not offered of *all* supply chain organizational elements, but only those that are directly related to topics to be reviewed in this document). In a similar form to the discussion of Dell's supply chain evolution, I offer below a summary of the major changes that occurred in the past few years to make Dell's supply chain *organization* much more complex, as well.

In the Beginning

In the beginning (1999), there were three groups in Dell's supply chain organization that managed what has been termed "Continuity of Supply" (the process by which demand is matched with supply). Those groups were Demand / Supply (focused on demand forecasting processes), Buyers (responsible for supply purchasing and supplier relationships, and Production Control (one group in each factory responsible for ensuring each factory has the supply it needs on a daily basis). All of the groups were located in Austin and most suppliers were also located nearby.

US Supply Base and Buyers Move to Asia, RSM's Added
Over the course of 2000 to 2005, Dell's US supply base migrated to Asia. In 2002, Dell realized that there would be significant advantages to also moving their US purchasing organization to Asia. Dell quickly acted, opening new offices and hiring new (local) buyers in multiple Asian countries. The buyers who had been located in Austin remained in Austin and either moved to other groups or became what was termed as "RSM", or Regional Supply Manager. These RSMs were to focus on a broader scope of supply issues, ensuring that there would be no problems over a 13-week horizon for their given commodity.

Ops Cell, SC3 Added
By 2003, Dell had begun to realize that there would be a benefit to centralizing the management of their manufacturing operations. Rather than maintaining a separate Production Control group in each factory, these groups were consolidated in Austin and termed the "Ops Cell" (with exception of a few liaison personnel who remained in each factory). This change was driven in large part by complexities introduced with the new "GeoManufacturing" policies that were previously discussed. Shortly after the introduction of the Ops Cell, a similar group was created to handle logistical operations, called the "Supply Chain Command Center", or SC3.

This was a significant amount of change to undertake over only five years, and there were many efforts ongoing to improve role definitions and organizational alignment when I arrived. It was hoped that the Dynamic Replenishment project would be yet another step toward helping to clarify roles in this complex organization.

In order to facilitate further discussion about the organization and roles that were affected by this project, it will be helpful to review the basic groups, roles, and processes as they existed when the project was initiated. For the purposes of this document, particular focus is needed on the supply chain groups that were directly involved in day-to-day matching of supply with demand to meet the needs of Dell's factories and merge centers. The discussion, therefore, may neglect more strategic or unrelated supply chain groups in the interest of maintaining proper scope. (Those groups include the groups responsible for long-term strategic supplier selection and pricing, for example, as well as the groups which own the strategic configuration of Dell's inbound and outbound logistics networks).

The groups that were relevant to this project were those that participate in cross-functional teams called "commodity teams". Each commodity team is responsible for ensuring consistent supply lines to meet demand for that commodity. The following diagram, with the exception of the SC3 organization, illustrates the roles that participate in these commodity teams. The SC3 role is included because, although they do not participate on commodity teams, they play a critical centralized function in the material balancing tasks of the commodity teams.

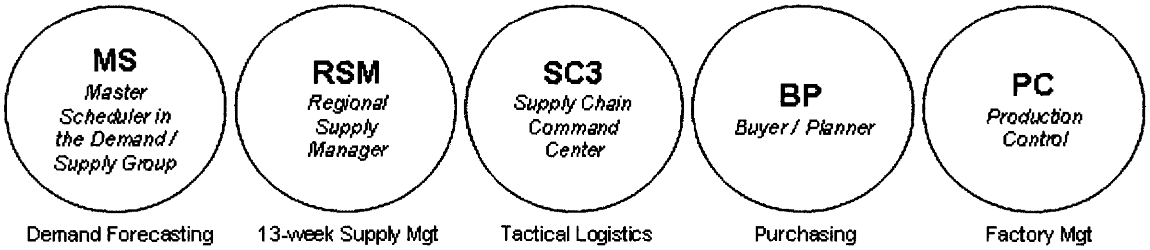


Figure 9. The roles involved in Dell's supply chain commodity teams.

Below is a more detailed explanation of these roles and their responsibilities as of June, 2005.

Demand / Supply (D/S): A team, primarily organized by commodity, that is responsible for understanding and forecasting weekly demand projections. Some particular responsibilities include issuance of weekly demand projections and associated hedging, projections of lead time extensions for customer delivery based on supply availability and other issues, tracking of large orders, and planning for product transitions. A member of Demand / Supply will often be referred to as a "Master Scheduler" (MS).

Production Control (PC): A team, primarily organized by commodity, that is responsible for ensuring that all factories' supply needs are met on an hourly basis. Some particular responsibilities include enacting product deviations (substitutions) or material transfers when a factory may run short of a part, tracking factory needs and inventory levels for proactive response, and communicating factory issues to other organizations so that proper actions may be taken.

Buyer / Planners (BP): A team, primarily organized by commodity, that is responsible for working directly with suppliers to issue POs for parts based on the weekly forecasts that are issued by Demand / Supply. This team is located in Asia, with exception of the buyers for the processor commodity team. Some particular responsibilities include the translation of part-level demand forecasts into supplier-level forecasts (based on pre-negotiated supplier percentages, called "TAM (Total Available Market) splits"), communication of supply needs (over a 13-week period, on a weekly basis) to suppliers, and taking actions needed to ensure supply is routed to the proper locations (e.g. material diversion or transfer requests en-route).

Regional Supply Managers (RSM): A team, primarily organized by commodity, that is responsible for ensuring that supply needs are going to be met continuously over a rolling 13-week period. Some particular responsibilities include a weekly industry report to all members of the commodity team, continuous tracking of supplier schedules and issues to ensure supply will meet demand over the next 13 weeks, and coverage for Buyer / Planners during Asian off-hours.

Supply Chain Command Center (SC3): A team that serves all commodities concurrently, responsible for carefully tracking and reporting the status of "hot" incoming supply and initiating corrective actions when immediate issues arise. Some particular responsibilities include the daily tracking of a list of "hot" parts (parts at risk of going short), initiating and coordinating site-to-site material transfers, and tracking key logistical metrics, such as daily backlog levels.

Examples of other relevant supply chain groups and roles include GSM/GCMs (Global Commodity/Supply Managers, responsible for longer term pricing and strategy issues), and Logistics (responsible for managing the supply network), among others. These are examples of roles that were relevant but not central to the Dynamic Replenishment project.

It is important to note that all of these groups and roles are primarily located in Austin, TX, with exception of the Buyer / Planners. That team is dispersed throughout Asia, based on for which suppliers a given Buyer / Planner is responsible.

As a visual reference, the following diagram offers an illustration of each group's position regarding the management of supply in the chronological supply chain, beginning with the forecast of supply needs from Asia (months ahead of production), and ending with production in US factories.

Figure 10. The role of various groups in Dell's chronological supply chain.

In order to understand the relationships between these roles, it will be helpful to review the process that is at the core of their responsibilities: the weekly demand forecasting process.

Weekly Demand Forecasting Process

The Dynamic Replenishment project was one that focused on the day-to-day management of inventory levels at Dell's various sites. In order to understand the steps that were taken as part of this project, it is first necessary to understand Dell's general weekly demand forecasting/supply management process. Below is a description of the weekly tasks performed by the groups described above in order to match supply with demand.

- A new demand forecast is issued, reviewed and revised by the Demand / Supply team, and sent electronically to the Buyer / Planners in Asia.

- PC reviews the new part-level forecast against current supply levels to ensure that all factories will have the supply they need to meet their demand for the upcoming two weeks. If tactical supply issues are encountered, the SC3 organization plays a key role in executing the logistical changes needed to meet factory needs.

- Buyer / Planners review the part forecast plan for inconsistencies and communicate potential problems back to the Demand / Supply team. Once issues are resolved, the

Buyer / Planners break out the part forecasts into "TAM splits", or the percentage of each part's demand that each supplier will provide based on contractual agreements. A report of required demand by part is sent electronically to each supplier (with only that supplier's data contained).

- Suppliers review the GDS's that they have been sent to assure that they can make the required production adjustments. Each supplier responds to the Buyer / Planner with a set of stated "commits". These commits are the amounts of each product the supplier will provide to each location, and the supplier becomes responsible for meeting these commitments. RSMs work with suppliers where necessary to resolve any near-term sourcing issues, especially for industry constrained parts.

- The Demand / Supply team consolidates the supplier-level commits back into part-level commits, creating "Demand Supply" reports which compare supply commits to demand at the part and site level for the upcoming weeks. They use these reports to determine if any parts need to be put "on lead time", indicating that any customer order requiring that part (given that there is no deviation for the part) will be delayed by a stated amount of time.

Needless to say, many other routines and processes exist in Dell's supply chain organization, but this particular process is the most relevant to matching supply with demand, and therefore to the Dynamic Replenishment project. In fact, this process – and its complications – are what drove the need for implementation of the Dynamic Replenishment project. The following section offers an explanation of the challenges that Dell faces in matching supply with demand at its increasingly dispersed factories and fulfillment locations.

3. Material Balancing at Dell

"Material Balancing" at Dell refers, in the most basic sense, to the ability to match incoming supply with demand at each fulfillment location (factories and merge centers). To an employee at Dell, there will be more specific connotations associated with the phrase. In Dell-speak, an employee would be likely to describe material balancing as "the effort to maintain the same DSI levels at all sites." This is because, at Dell, inventory levels are measured in units of DSI, or "Days of Sales Inventory". This quantity is given by the inventory count of a part divided by the daily forecasted sales for that part. For example, if Dell has 500 of Part A and average forecasted demand over the upcoming week is 50/day, then it has 10 DSI of Part A.

Dell's maintains a consistent DSI goal for "standard" parts, where non-standard parts might include a plastic connector that costs little to purchase and store at much higher levels than standard parts. This goal is clearly communicated to suppliers, and suppliers are responsible for ensuring that the SLCs continuously hold that minimum level of DSI for each of their parts. This policy has served Dell well, although there are debatable aspects of its efficacy. For example, a part that typically runs at extremely low volumes may go on severe shortage if a large order for it is placed. Similarly, it is likely that the same DSI level is not the optimal inventory level for all types of parts, and a number of Dell employees are working to enhance the metric to accommodate this notion. However, it is not the focus of this project to question this policy, and discussion will be advanced with the assumption that the policy will remain in place.

3.1 Material Balancing Challenges

At Dell, employees make things happen. That is to say that, when something goes wrong, a culturally driven "can-do" attitude takes over. For example, if sales run low on a given item, promotions are immediately put into place in order drive down stock levels and maintain market share. Similarly, if a part runs low in the factory, little time will pass before a manager is on the phone scheduling a transfer of material or a demand manager has modified website promotions in order to re-direct customers to a similar part that is in stock (referred to as "demand shaping"). This attitude and way of doing business has served Dell extremely well and is likely to in the future. However, this culture of immediate execution at all levels in Dell can sometimes mask trends that exist as a result of underlying issues (since individual symptoms are resolved with such expedience). That is what happened to Dell with material balancing.

For years, material balancing was not a problem for Dell, as it had only one location. In the past five years, however, two new factories and a number of new merge centers have been constructed in five different states. As these new locations began to be introduced, Dell's employees quickly adapted to the need for material movement between sites. Site-to-site material movements (typically referred to as *transfers*) became frequent and the ad-hoc re-routing of incoming supply (or *diversions*) was not uncommon. When Dell had only two sites (Austin and Nashville), this was not an insurmountable task. Even as Dell added new merge centers in Ohio and Reno, employees coordinated well and ensured that material was always where it needed to be (note that merge centers do not have as significant of an impact on material balancing complexity since merge center orders are easier to shift from site to site than factory orders). By 2003, material balancing had become more challenging for Dell, but management lacked visibility to the issue as most of the problems were resolved quickly without escalation. This lack of visibility to material balancing challenges changed around 2003, when a number of critical parts became industry constrained. Inventory balancing problems for these commodities became much more difficult to address as supply ran short and transfers became more complicated and frequent. As a result, the material balancing problem at Dell eventually presented itself in three forms: logistics costs, part shortages, and organizational complications.

3.2 The Material Balancing Problem: Logistics Costs

Dell tracks a number of indicators in order to monitor its total "cost per box", which serves as the ultimate operations cost indicator. One key element of this cost is the quarterly amount of money spent on transportation and logistics. Much of this logistics cost is steady, based on regular ocean and air routes for routing shipments of parts. However, a larger and larger portion of it can be attributed to a category called "expedites". An expedite occurs when, for any of various reasons, parts are needed at a factory more rapidly than normal. This occurs, typically, when a factory faces an imminent shortage of a part. Reasons for this may include low forecasts, large customer orders, or sales promotions (often through Dell's well-known "demand-shaping" strategy), among others. In fact, there are so many drivers behind the need for these expedites that Dell has established an official categorization hierarchy for their cost buckets. The following chart and explanation offers the detail of this hierarchy.

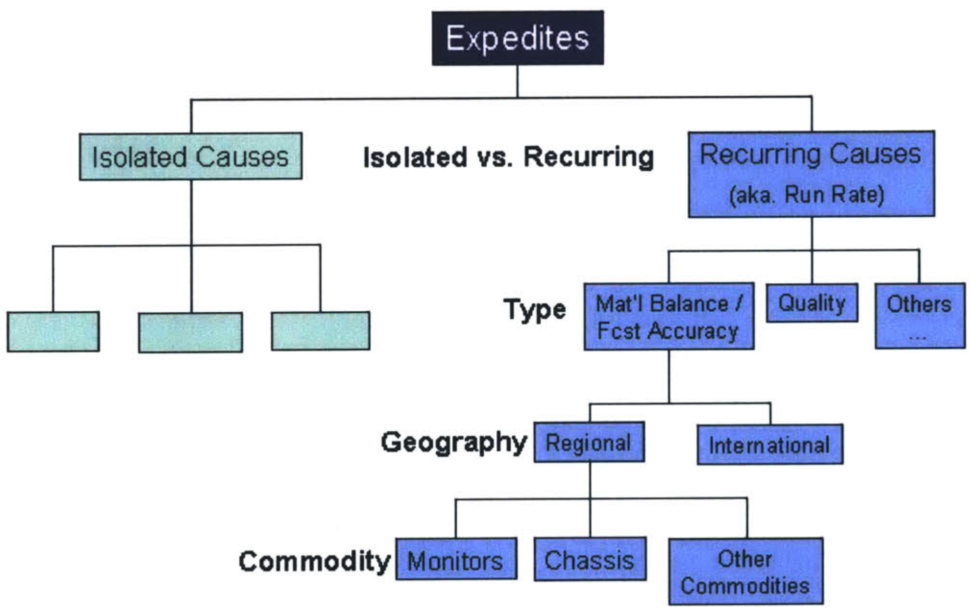


Figure 11. The categorization hierarchy of various types of expedite costs at Dell.

<u>Expedite Categorization Hierarchy</u>

- *Isolated* vs. *Recurring* Causes: The purpose of this split is to identify the expedite drivers over which Dell has little control. They call these "isolated causes". For example, if Dell is forced to switch suppliers for some reason, they will likely suffer a shortage in parts due to the rapid supplier transition. "Recurring Causes" is the bucket that includes factors over which Dell does have more control and for which it should implement improved processes. This bucket includes:

- Expedite *Type* – This explains the true root cause of the expedite. For example a part shortage may occur because of a *material imbalance* (one site is short on a part while another has too much of the same part) or a quality issue (defect issues on a part cause a shortage).

- Expedite *Geography* – This is simply a separation of US-based expedites (US site-to-US site transfer) and world expedites (which may include air expedites from Asia to the US or Europe to South America, for example).

- Expedited *Commodity* – This is the commodity category into which the expedited part falls.

In the past few years, these types of cost have increased at a fast pace for Dell. A presentation was given to Dell's management in the second quarter of 2006 that quoted expedite costs in the tens of millions per quarter after having risen steadily for two years. The following is a chart of Dell's quarterly expedite spend from Q4 of FY03 to Q2 of FY06, indicating a very rapid increase.

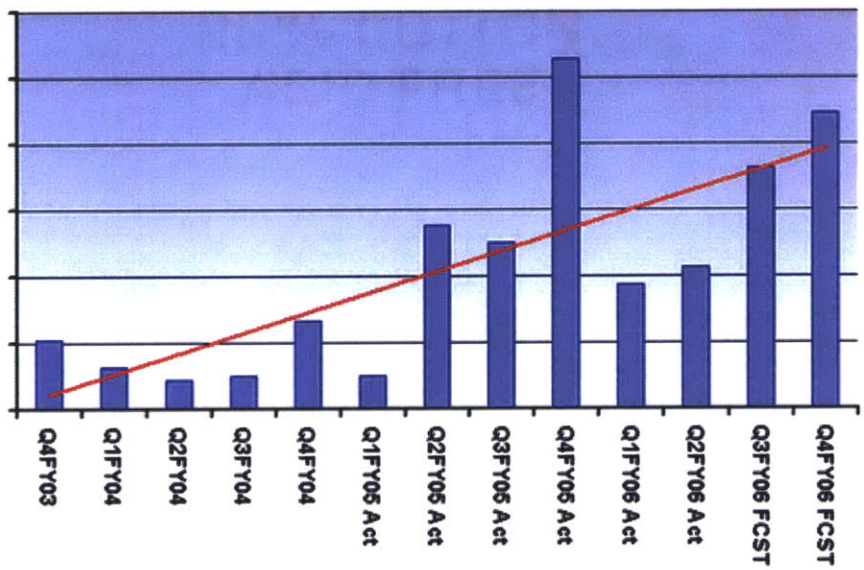


Figure 12. Dell Americas Quarterly Expedite Spend Q4 FY03 – Q2 FY06.

After this information was presented to supply chain mangers in Q2 of Dell's FY06, a challenge was issued to understand the drivers for these costs and bring them down. This marked the beginning of the evolution of the expedite cost hierarchy and the efforts to bring down costs in every category.

3.3 The Material Balancing Problem: Part Shortages

The second way in which the material balancing problem revealed itself was through increased numbers of part shortages. Part shortages are a critical indicator for Dell, as the company prides itself on customer service and on-time deliveries. Many part shortages will result in multiple orders being placed on backorder, delaying customer deliveries. As Dell added more and more sites and products, demand disaggregation (as discussed in previous sections) led to more and more shortages. Also, increasing world supply constraints of various PC parts complicated this issue. Rough shortage estimates for the Americas Region revealed that shortages had increased significantly in 2005. As a result, multiple site-to-site expedites were being performed every week at significant cost.

These levels of shortages did not occur for all types of parts and commodities. The commodities hit hardest by increased shortages were those whose industry capacity was constrained and which were large and bulky to transport. These combined factors led to higher shortage incidents, and higher costs required to "fix" the shortage through logistical expedites. I will refer to the commodity that best met this profile as "Commodity 1". The entire industry for Commodity 1 was capacity constrained, and it was expensive to transport due to size and weight. These factors drove Commodity 1 to the head of the expedite cost driver list, along with commodities that had similar characteristics. The following chart depicts contribution by commodity to regional expedite costs for Dell that were attributed to the material balancing issue in Q2 of 2005 (commodities are unidentified for purposes of confidentiality).

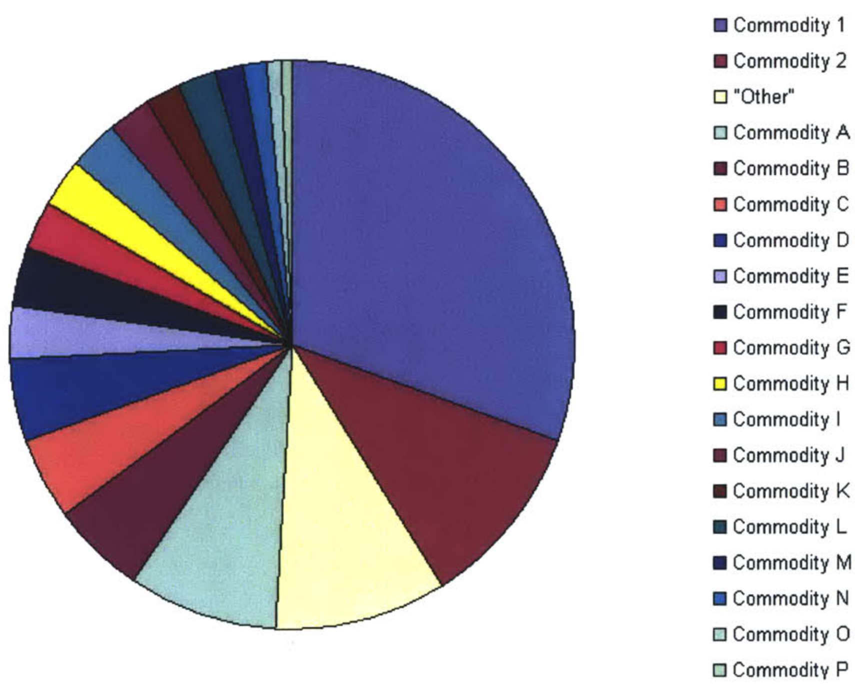


Figure 13. Contribution, by commodity, to Dell's costs for regional expedites attributed to material balancing problems in Q2 of 2005.

3.4 The Material Balancing Problem: Organizational Complications

Finally, the last way in which the material balancing problem manifested itself was through new organizational complications. As is apparent in Figure 10, there are often up to *five* organizations that have a stake in managing material imbalances. Because this problem (material imbalances) evolved so organically, each of these groups slowly took on various responsibilities for managing the problem, with ad-hoc coordination amongst themselves as needed. Although

Buyer / Planners were eventually assigned official responsibility for "campus balancing", it proved challenging for them to coordinate and own the entire process.

3.4.1 Material Balancing Processes

Before discussing the complications that arose, it will be helpful to briefly describe the typical steps involved in material balancing decisions. In Dell's extended global supply chain, there exist *two* types of material balancing decisions:

> 1) decisions regarding immediate actions to transfer or expedite material, referred to as *transfers* (site-to-site movement of material) or *expedites* (shipping material to its destination by truck rather than rail in order to expedite its arrival) and
>
> 2) decisions regarding the final destination of ocean-shipped material that has not yet reached a US port, referred to as a *diversion.*

The processes for these two decisions were somewhat independent of each other before the project implementation. The following describes the basic steps and ownership in each process.

<u>Material Balancing Process: Transfers and Expedites</u>

1) *Material imbalance is identified* – This frequently occurred during a weekly commodity team meeting (where the MS, RSM, and PC reps were typically present), but often occurred randomly throughout the week as various team members recognized imminent factory shortages in the course of their work.

2) *Imbalance is communicated* – The identifying group members sends an email to the commodity team in order to advertise the shortage and find out if anyone has information regarding the shortage (are there available part deviations? from where can we transfer material?, etc.)

3) *Ownership is determined* – In an ad-hoc manner, ownership of executing the transfer or diversion needed to address the imbalance is assigned to a group member. If the request is urgent, the RSM would often take ownership, and if not, a request would be sent to the BP to take care of the issue the next day (due to time zone delays).

4) *Request is submitted* – The owner of the issue submits an official on-line request that goes to the Logistics group (which is part of SC3). A separate email must be sent to the supplier who owns the inventory being transferred, because that supplier still owns the inventory and a release must be obtained.

5) *Request is clarified* – For each transfer, a typical flurry of anywhere from five to fifteen emails are exchanged between SC3, the supplier, and the commodity team in order to address details of the request.

6) *Transfer / Expedite is executed* – Material is transferred or expedited.

Material Balancing Process: Diversions

1) *Need for diversion is identified* – Once a week, BPs bring together information on Dell's current inventory status, incoming supply, and forecasted demand by part, and review it with each supplier. They jointly decide which material should be assigned a new destination in order to accommodate demand shifts that occur while that material is being transported on the ocean.

2) *Details are clarified* – Where necessary, emails are exchanged in order to clarify the information surrounding the diversion request, such as current inventory levels or forecasted demand levels.

3) *Diversion request is submitted to the supplier* – The BP (or sometimes the RSM due to time zone issues) sends an email to the supplier who owns the inventory to request a BOL (Bill of Lading) change.

4) *Diversion request is submitted to the carrier* – The supplier sends a request to the ocean carrier to ensure that it is not too late to execute the diversion (a BOL cannot be changed once material is within 48 hours of its US port).

5) *Diversion costs are communicated* – Once carrier approval is received, the supplier seeks approval from the BP for any additional costs incurred with the diversion.

6) *Diversion costs are approved and diversion is executed* – The BP approves the costs and the BOL for the shipment is changed

3.4.2 Material Balancing Process Difficulties

As may already be apparent, a number of difficulties arose in the execution of these processes. The following list outlines a few of the organizational complications that arose as material balancing became a prominent issue.

- *BP Challenges*: Buyer / Planners (BPs), in particular, faced two major difficulties in executing responsibilities associated with material balancing:

    - Time zone issues: BPs were unable to react to problems (usually part shortages) that occurred during US daytime hours, which is when most problems were found. These issues had to either 1) be addressed the next day upon sending an email to the BP, or 2) be escalated to the RSM, who was the designated backup for the BP.

    - Proximity issues: Many transfer / expedite requests require close interaction with Dell's SC3 organization in order to determine availability, timing, etc., as well as to optimize the use of Dell's logistical resources. These communications were very difficult for BPs, due to their distance from this group as well as time zone differences. As a result, much important information was often not communicated, or was misunderstood, resulting in inefficient logistical operations for these transfers and expedites.

- *Redundant Efforts*: Since the commodity team recognized that BPs would often not be able to resolve balancing issues quickly enough, many took responsibility themselves for this task (as suits Dell's culture of immediate execution). This led to redundant efforts being performed to track relevant information (demand forecast, current inventories, and incoming supply) as well as, on occasion, redundant requests being submitted for the same issue.

- *Data misalignment*: As team members concurrently evaluated inventory levels and other related information – often from different sources – multiple discrepancies would lead to drawn-out conversations (typically over email) to drive data resolution. For example, any given team member had at their disposal at least three varying sources for forecasted demand levels and even more sources to track current inventory levels.

- *Role misalignment*: As RSMs spent more and more time covering for the BPs due to time zone and proximity issues, much focus on core elements of their role was lost. The RSM role had been designed as a *strategic* role, with commodity representatives being responsible for understanding the three-month outlook for all sourcing for all parts within their commodity. Executing day-to-day transfers and diversions for material balancing did not make sense within this role definition, yet the RSM had taken on a significant portion of these responsibilities. The same dilemma also applied to the MS (Master Schedulers in Demand / Supply) role. They were responsible for understanding demand, by part, for their commodity over a three-month timeframe, among a number of other responsibilities. Execution of tactical daily material balancing tasks often took away from the necessary demand forecasting requirements of this role.

- *Reactive processes*: Proactive material balancing decisions were only made once per week (once for diversions and once for transfers / expedites). As a result, if any major demand or supply changes occurred throughout the course of the week (and they did nearly every week), resulting balancing problems would not be identified until a part shortage was imminent or had already occurred. This led to increased shortages, and placed a significant strain on team members' time as they shifted to 'panic mode' in order to address these problems.

- *Communication delays*: The exchange of multiple emails in order to validate details often led to delays measured in days for actions that were needed within hours.

Before initiation of a project to help improve these processes, a survey was conducted in order to understand and roughly quantify the organizational impacts of material balancing problems. This survey was conducted by myself and the Dynamic Replenishment project co-manager. Questions were submitted and responded to through a web service (Surveymonkey) typically used by Dell to perform surveys. The survey was sent to all supply chain groups which are most involved in material balancing processes: Production Control, Buyer / Planners (referred to in the survey as China Procurement), SC3, Demand / Supply, RSMs (referred to in the survey as Regional Procurement), the Ops Cell (which performs functions similar to those of Production Control), Logistics (in particular, those members of the Logistics team who were involved in coordinating material balancing activities with Dell's primary ocean carrier), and Customer Experience (a fulfillment group responsible for ensuring on-time customer deliveries). Both list-based responses as well as full text responses were sought, depending on the nature of the question.

Appendix A shows the distribution of respondents from each group polled, in magnitude and percentage of total possible respondents. The appendix also contains the results for two of the survey questions, indicating that seven of the total 50 respondents spent 10+ hours per week on material balancing issues, and "Clearer Role Definition" and "Designating Balancing Ownership" were the top two improvements suggested to help improve the balancing process. (Interestingly, these were ranked above the improvement of information systems, which was initially anticipated to be the number one response).

Given the numerous material balancing challenges faced by Dell – rising expedite costs, increasing part shortages, and organizational complications – it is not surprising that Dell's supply chain management embarked on multiple efforts to decrease the instances of material imbalances. These efforts included forecast improvement, part standardization, and re-evaluations of inventory levels, among others. I was brought in amidst these efforts, to evaluate and potentially execute a project to enable a more proactive process for the re-routing (through diversions) of material and improve the tools used to do so.

4. Proposed Solution: Proactive Material Balancing

The proposed project, which was already broadly defined upon my arrival, would re-route ocean-shipped material, where needed, at the latest moment possible (which was 48 hours before material arrived at a US port). This would effectively *reduce the forecast lead time*, albeit in a restricted sense because the aggregate amount of supply could not be increased or decreased at this late point in the supply chain. The following diagram illustrates this concept, which is that what is typically a 60-day forecast would be reduced to a 14-day forecast by re-routing material, as needed, when it arrives at the port (14 days is the maximum amount of time it takes to ship material from the port to a Dell factory by rail).

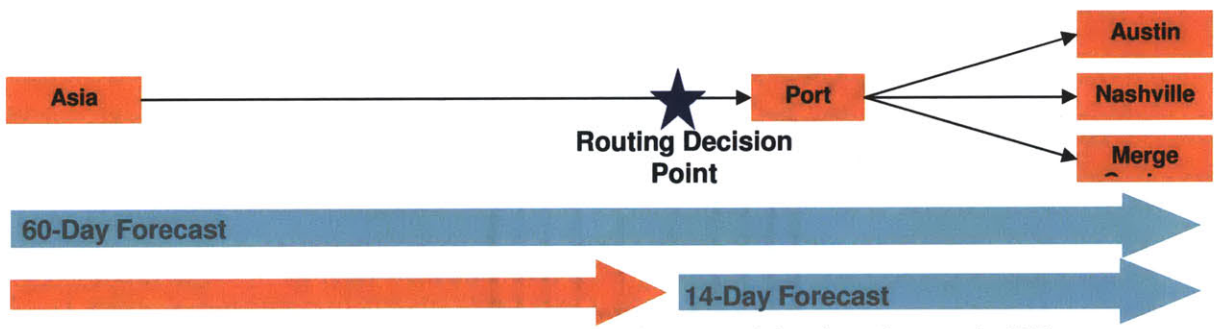


Figure 14. The effects on forecast lead time of re-routing material as it arrives at the US port.

The potential cost savings from this proactive re-routing of material were undisputed. The cost to proactively re-route a container was minimal (a nominal fee for changes to the bill of lading), while the cost of a *single* truck for a site-to-site transfer would average 10 to 13 times the diversion fee, and could range to 50 times the diversion cost depending on market conditions. These transfer costs could become significant, as multiple trucks were often required for a single part transfer (especially for larger parts).

Although this action was already occurring (performed by BPs and suppliers), it occurred by exception and only once per week. This lack of frequency was driven by the fact that material balancing decisions were regarded as ones that had to be made cooperatively by the buyer *and* supplier. Given this requirement, buyers chose naturally to execute these decisions during their weekly phone meetings with suppliers, rarely initiating proactive diversions throughout the rest of the week. As a result, numerous opportunities for proactive balancing were slipping through Dell's fingers as demand levels and other factors changed throughout the week. Also, the BPs and suppliers had a tendency to use information that was three days to one week old, and would base decisions on demand and inventory levels that had most likely changed. These problems, as well as the complications illustrated in the previous section, drove a need for a more streamlined, centralized, and proactive material balancing process.

The project designed to accomplish this had been termed "Dynamic Replenishment", indicating that the routing of material to factories would become a dynamic process (whereas before few changes were made to material destinations en-route). When I arrived at Dell, some preliminary work had already been done on the project, but a complete review of its potential had not yet been conducted, and this is where I began.

4.1 Anticipated Project Benefits

Before embarking on this project, it was necessary to follow preliminary steps as outlined by Dell's BPI (Business Process Improvement) process. This is a structured and monitored process to be applied throughout the course of all major improvement projects at Dell, and has touted success in the numbers of billions of dollars per year in cost savings. The process follows closely in the footsteps of six-sigma processes, encouraging the use of structured problem solving methods and thorough data analysis. With regard to this project, this meant that a key first step would be to conduct a cost-benefit analysis in order to determine anticipated benefits against which the success or failure of the project could be measured. These benefits were ultimately stated in two categories: cost benefits and organizational benefits.

4.1.1 Cost Benefits

The ultimate goal of this project was simple: get material to the right place at the right time. This would be accomplished by routing material at a later point in the supply chain – similar to the idea of postponement of product differentiation. If successful, significant cost benefits were anticipated from this project as a result of reduced part shortages, which would lead to reduced logistical costs to transfer or expedite parts. In estimating potential savings, the first step would be to determine how much money was currently being spent on these complications.

I was fortunate that, a year or so before my arrival, Dell's finance organization had just begun tracking expedite and transfer costs more carefully. I therefore had a significant amount of data upon which to draw. In evaluating this data, it became readily apparent that there was a significant amount of expedite cost that this project would *not* impact. Since the project focused on ocean shipments only, any air freight costs (which accounted for a significant portion of total expedite cost) were out of scope. Also, any part shortage caused by anything other than a material imbalance (e.g. quality issue, supplier issue) was beyond the project scope as well. Once these expedite costs were factored out, it was determined that the total savings potential for reduction of material imbalances was about 10% of Dell's total annual expedite costs. (Although this percentage may at first seem trivial, it accounted for a significant amount of annual dollar savings measured in millions.)

The 10% savings was the amount that could be saved if *all* material imbalances were eliminated. However, the elimination of 100% of material imbalances would be impossible, as that would reflect total elimination of forecast error. Therefore, the next step was to determine what portion of the 10% could feasibly be saved through this project. A deductive approach was taken, by assuming that there were certain factors in driving this cost that the project could not eliminate. Those factors included:

- *Demand variability*: Demand variability is reasonably high for Dell, especially given large orders that frequently come in from business customers. As a result, Dell's forecast accuracy goals are often as broad as plus or minus 20-25% of actual demand. In order to estimate this effect on material balancing, we estimated how often a diversion would be "incorrect" (meaning a diversion was executed, but demand shifted in such a way, after the fact, that the diversion was not needed). Since no historical information on this had been tracked, our experience-based estimate was approximately one in every five diversions, or 20%. Therefore, the estimate of impact of demand variability was assumed to be 20%.

- *Supply variability*: Supply lines for many of Dell's parts have a tendency to be "chunky", arriving in large amounts at reasonably large intervals (1-2 weeks). This reduces day-to-day flexibility in adjusting the routing of supply. The impact that supply variability has, then, is to increase the *magnitude* of the impact of an incorrect diversion, since longer intervals between shipments means *larger* shipments. In other words, it amplifies the impact of demand variability. For example, a shipment (with a ten-day delivery frequency) of 10,000 parts might be incorrectly diverted. If those parts had been shipped in a more frequent interval of 1,000 parts per day, then it is likely that the mistake would be caught before *all* of the parts were diverted. An assumption was made that half of every incorrectly diverted shipment could be salvaged were it a daily shipment. Since 1/5 of diversions were assumed to be incorrect (as noted above), then the estimate of the impact of supply variability was 1/5 times 1/2 (the salvageable amount of each incorrectly diverted shipment), or 10%. In the interest of a conservative cost savings estimate, the estimate of impact of supply variability was also raised to 20%.

- *Demand disaggregation*: As previously discussed, the introduction of a new factory (in North Carolina) would inevitably increase overall demand variability as a result of demand disaggregation. The square root law of disaggregated demand indicates that, for two factories, inventory levels must increase by $\sqrt{2}$, or 41%. As Dell added a third factory, the aggregate inventory impact would be $\sqrt{3}$, or 73%, for an increase (over the two factories that Dell already had) of 32%. Based on Formula 1 ($s = x_L + k\sigma_L$), we can say that an increase in s of 32% should require an increase in safety stock ($k\sigma_L$). However, since most parts that cause material balancing problems are industry constrained, it is not possible to increase safety stock levels. As a result, the service level is decreased by approximately 25%. Since a lower portion of Dell's demand would be met out of the third factory than in the first and second factories, the estimate of service level reduction was reduced to 10-20%. Again, in the interest of a conservative estimate of cost savings, the out-of-scope impact of the addition of Dell's third factory was assumed to be 20%.

These estimates are based on "back-of-the-envelope" calculations, and this was intentional. Project managers were seeking an order-of-magnitude estimation of project benefits, and the additional effort required to ensure high levels of accuracy would have been significant. Our idea was that the estimate should be conservative, so that managers understood the *minimum* potential benefit of the project. Given the conservative estimate (based on the above calculations) that each out-of-scope impact accounted for 20% of material balancing costs, we estimated that Dynamic Replenishment could reduce material balancing costs (the costs which represented 10% of total expedite costs) by about 40%, presenting a quarterly savings opportunity of that remained significant in terms of absolute dollars. (This estimation has as assumption built into it that the Dynamic Replenishment project would be applied to all commodities. This became a topic of concern over the course of the project, and will be revisited in a later section.)

4.1.2 Organizational Benefits

The third, an much more difficult to quantify, benefit of the Dynamic Replenishment Project was improvements to Dell's supply chain organization. As discussed in previous sections, Dell's supply chain organization had become much more complex in recent years, and material balancing processes in particular had become quite cumbersome. The organizational survey that was conducted (Appendix A) underscored the need to clarify material balancing roles and eliminate redundant efforts. In light of this, specific organizational objectives for the Dynamic Replenishment project included:

- Clarify ownership of material balancing tasks.
- Document material balancing processes and identify opportunities for improvement.
- Reduce redundant material balancing efforts among commodity team members.
- Reduce the overall amount of collective time spent by commodity teams on material balancing tasks.
- Improve and consolidate the information systems and tools needed for material balancing tasks.

Although these benefits would prove highly difficult to quantify, there existed an argument that their benefit should equal or surpass that of the cost savings. The reason for this was the current state of some commodity teams in Dell's supply chain organization. A number of these teams, especially those involved with industry-constrained commodities, found themselves shorthanded in dealing with unremitting supply problems. Constant analyses, communications, and off-hours meetings were required to ensure Dell always had the supply to meet its demand. These factors were leading to problems such as high turnover rates and employee dissatisfaction. In this regard, one may argue that the "soft" benefits of a project (clarifying roles, reducing time spent on tasks, etc) may have a more significant impact on Dell's supply chain operations than cost reductions in millions of dollars per year. Throughout the Dynamic Replenishment project, most managers agreed that organizational benefits of the project carried at least as much weight as the monetary benefits.

4.2 Project Proposal

Although the goals of the project had clearly been established, there remained the question of how to accomplish those goals. The project team (myself, a project manager, and the commodity team) faced questions such as: Who should own material balancing? Should responsibility for material balancing lie with one person for all commodities? Does the answer lie in organizational changes or changes to the current tools and resources? Over the course of a few months, the team's answers to these questions evolved as we learned more about the material balancing process. The following list reflects all of the options that were considered as solutions to the material balancing problem.

1) *A US-based owner designates routing for all material upon port arrival.* This option reflected a major shift in operations in that it suggested that BPs in Asia would no longer

assign a US destination to material. All destinations would instead be assigned by a US-based "Routing Analyst" as material arrived at the US port.

2) *Asia-based BPs own material routing, with improved resources.* This essentially reflects what the status quo was (BPs owned material routing), but acknowledges the need for enhanced tools and resources in order for the BPs to make better decisions. When operating from "the other side of the world", real-time and accurate information resources are critical to making the right judgments.

3) *A US-based owner designates routing for material, by exception, upon port arrival.* This option is similar to Option 1, but is much less of a change since material would still leave Asia with a US destination, and those destinations would simply be reviewed by the routing analyst for necessary modifications depending on conditions when material arrived in the US.

4) *US-based commodity team members own material routing.* This option maintains what was the current practice of having one person on each commodity team own material balancing, but transfers ownership from Asia to the US. The reasons behind this are time zone alignment as well as proximity to critical logistics organizations for quick decision making.

Initially, the preference was Option 1. Perhaps what Dell needed was to be forced to make a routing decision for all material as it reached the port, so that none of it could possibly end up at the wrong destination. However, we soon learned that there were logistical restrictions to this, such as the requirement for BOLs to have a final destination upon departure from Asia and a per-container fee for each BOL change. These costs would add up too quickly to make this a viable option. The next option considered was an improvement in the information tools and resources used by the team for material balancing. It seemed apparent that, if we could just get the right information in the right hands at the right time, the material balancing decision would almost be a trivial one. In researching this option, however, we quickly realized that Dell's IT resources were far too constrained to achieve the goals we had in mind. Also, the more we talked with commodity team members about the material balancing problem, the more we came to the realization that this was first an organizational problem, then an IT problem. A sound foundation of processes and clear roles was necessary before IT solutions could reach their full potential. For these reasons, we chose not to focus on an IT-based solution. The final two options both had a common appeal – the idea of US-based material balancing ownership. For the reasons outlined in previous sections, we felt strongly that US-based ownership would alleviate cumbersome time zone and communication issues that led to delays in urgent decisions. In deciding between the two, the key factor became the idea that commodity teams could be freed of their time-consuming material balancing tasks by having a single person (or group of people) take over this responsibility. Also, Option 3 presented the opportunity to streamline the decision-making process and apply new decision support tools to material balancing for *all* commodities, whereas in the current state not much learning was shared among the commodity teams.

This analysis showed that option three was the strongest and most practical one. Therefore, our proposal was to institute a new role in Dell's supply chain organization that would focus solely on material routing and balancing in the US. Significant changes such as this, however, are difficult to implement without a degree of validation through experimentation. Consensus was easily reached that a small scale pilot of the new role was necessary to validate the benefits of full implementation.

4.3 Pilot Plan

The following were the details of the pilot to be implemented and the reasons for those decisions.

- *One commodity would be piloted.* In order to maintain a small scale pilot that would allow for in-depth learning, the pilot would only involve one commodity. As mentioned previously, "Commodity 1" accounted for the largest percentage of material balancing expedite spend, and so was the obvious choice for a pilot commodity.
- *The routing analyst would be considered part of the SC3 organization.* This is because physical proximity to tactical logistics groups was critical to the tasks of a routing analyst, who would be executing a number of re-routing and expedite activities on a daily basis.
- *Pilot duration would be three months.* This amount of time allowed for the routing analyst to become relatively proficient at the role and to have a tangible impact on material balancing activities for at least a month.

The pilot would be conducted jointly by myself and a dedicated Dell employee named Julie Summers. Julie was intended to assume the new role permanently if the role were determined to be beneficial during the pilot. Appendix B illustrates the timeline for the entire project, including the planned pilot.

5. Pilot Execution and Results

Two major efforts were necessary in order to get the pilot underway. First, information critical to material balancing tasks, such as demand forecasts, incoming supply, and inventory levels, needed to be better consolidated to facilitate quicker decision-making. Second, a new weekly material balancing process needed to be defined and agreed upon by the commodity team for the piloted commodity.

5.1 Pilot Execution: Improving the Resources

Improvements to material balancing resources was a critical element to the success of the pilot. Using the tools that existed before the pilot began, data consolidation to support material balancing decisions took at least one and often two days. This would be unacceptable during a pilot that required material balancing decisions to be made on a daily basis. This section will offer a review of the improved material balancing model that was created. However, it is first necessary to review the logic behind material balancing decision, so that the application of the model may be easily understood.

5.1.1 The Material Balancing Decision at Dell

Material Balancing Actions

As reviewed in Section 3.4.1, there were three types of material routing actions which could be taken to impact material balancing. The type of action taken was typically determined by the point at which material resided in its shipment when the decision was made. The following is a list of those actions in order of the most proactive (earliest in the shipment) to the most reactive (latest in the shipment).

> *Diversion* – Changing the destination of a container (or containers) while still on the ocean. Specifics include the fact that, due to paperwork considerations, the redesignation had to occur at least 48 hours before the container reached a US port. Also, only containers that contained a single type of product could be re-routed. The cost of this action was a minor per-transaction fee (where a single transaction may involve multiple containers on the same ocean carrier).
>
> *Expedite* – Expediting the transport of a container (or containers) from its US port arrival to its final destination. This meant changing the mode of transportation from rail (the default mode for all locations except Reno which always used trucks) to truck. The costs of these transactions varied depending on the final destination. Expedites were also required to be requested at least 48 hours before arrival at a US port. During the pilot, no expedites were conducted and this type of transaction was not considered in the final analysis.
>
> *Transfer* – Site-to-site movement of material that occurs when inventory has become unbalanced. If one site runs short on a part and another site has excess supply, the material from the latter site will be transferred to the former. This type of transaction was the most common type and was also *very expensive* (as previously mentioned, about 10 to 13 times the cost of a diversion for a single truck). Specific costs depended on the

distance between the originating site and the receiving site (and other logistical factors such as terrain, season, and truck availability). Cost was independent of whether or not the load was partial or full, and did not vary with weight or piece count. As a result, trucks for large parts were far more cost prohibitive than for smaller parts. Transfers could occur at any time (assuming truck availability), and the shipment time from one site to another averaged about three days.

The Material Balancing Decision

The material balancing decision was grounded in two, often opposing, objectives. The first (in number and priority) was to avoid shortages of any parts at any factory, and the second was to minimize logistical costs (shipment, transfers, expedites, etc). The prioritization of these goals was driven by Dell's determination to *always* meet customer shipment expectations, which meant avoiding part shortages at nearly any cost. As a result, our goals, in order of priority, were to 1) initiate any transaction necessary to avoid part shortages and 2) drive the initiation of cheaper, more proactive transactions (namely *diversions*) in place of the expensive site-to-site transfers which had become the norm.

Since our mandate was to avoid shortages at nearly any cost, we did not make decisions based on a trade-off of logistics costs vs. shortage costs (also, no reliable estimate of shortage costs had been presented at Dell and we decided not to invest time in this given that we were to avoid shortages regardless of the costs). The success of our decisions, then, would be gauged purely by reduction of logistical costs and part shortages. We settled quickly into a decision routine that accommodated these objectives, and the following is an outline of that decision algorithm (note that a model called the "Material Balancing Tool" was used to support this process and will be described in detail in the following section).

1) Review all parts, by site, for *immediate shortages*. Based on current inventory, scheduled supply, and forecasted demand, if a part is anticipated to go short before its next shipment arrives, then a site-to-site transfer will be required. For each transfer:

    a. Research whether or not any deviations exist for the part that are not taken into account in the balancing model. If a deviation exists, try to shift demand from the part that is short to the deviatable part.

    b. Verify all critical information – especially supply information. Often, available parts would not show themselves in Dell's systems, and a significant amount of manual intervention was necessary in order to confirm that the part was indeed short.

    c. Estimate how many pieces will be required to support demand at the site that is going short until the next shipment arrives.

    d. Determine which site has the most excess supply from which to pull. If more than one site has excess supply, the decision may be made based on distance to the receiving location in order to minimize time and costs.

e. Determine how many trucks to ship and initiate the transfer through a web-based logistics application.

f. Log the anticipated transfers in the material balancing model so that those plans will be taken into account during step #2.

2) Review all parts, by site, for *future* shortages or imbalances (in which one factory is anticipated to have significantly more inventory – in terms of DSI – than other factories which use the part) that exist within the *diversion timeframe*. (This timeframe was different for each site, since the travel time to each site from the US port was different. For example, the diversion timeframe for Reno was nine+ days because a container was assumed to spend about three days at the port and four days in transit – with an additional two days because of the 48-hour pre-port notification requirement. Similarly, the diversion timeframe to Austin and North Carolina were 15 days and to Tennessee 14 days. This meant that decisions to divert material from Austin, North Carolina, and Tennessee had to made much farther in advance than a decision to divert material from Reno.) This step was considered most critical during the pilot because these were the actions that would *proactively* re-route material – at very minimal cost – before it arrived at the wrong site and had to be transferred on expensive trucks. The following steps were performed for each diversion:

    a. Research possible part deviations (same as step a for the transfer process).

    b. Verify all critical information (same as step b for the transfer process).

    c. Estimate how many pieces are required to meet demand until the next shipment arrives.

    d. Determine if there is a shipment or shipments going to another factory which can be re-routed based on that factory's diversion timeframe. If more than one site has available supply to re-route, choose a site based on which shipment will arrive sooner at the receiving site (this required verification of the scheduled port arrival date through an online tracking application owned by Dell's carrier).

    e. Determine the number of containers to be diverted. Ideally, an amount will be diverted such that the originating and receiving factories' DSI levels are equal (i.e. material "balancing"). However, given the supply line, this may or may not be possible.

    f. Request the diversion. This process took about a day and involved:
        i. detailed verification of container numbers, quantities and scheduled arrival dates
        ii. sending an email to the supplier of the parts in order to obtain diversion approval
        iii. waiting for the supplier to send an official diversion request to the carrier and receive a response

iv. documentation of approval or rejection of the diversion request

These decisions could not have been made in any reasonable amount of time without an interactive tool to facilitate them. This tool needed to consolidate demand, supply, and forecast information for all parts by location. This information would be used to reveal daily DSI levels for each site over a given timeframe (about six weeks). Given this information, a user would then be able to input planned transfers and diversions such that shortages would be prevented and DSI levels would be relatively balanced across all sites. I found such a model that was being used by the pilot commodity team and enhanced it so that it took significantly less time to update and was more user friendly. The following section details this model and how it was used during the pilot.

5.1.2 A New Material Balancing Model

Since the team had agreed that this project was not to be an IT-intensive one, the solution to bring together necessary information would be a simple, "homegrown" one. Steps were taken to obtain consensus from the commodity team on single POR (Plan of Record) sources for each type of information required. For example, one of the three+ demand forecast systems, called MRP, was selected as the single source for demand information. This agreement drove accountability to the respective owners of the information to ensure that the chosen source was always correct. The agreement also (theoretically) eliminated the need to the routing analyst to validate information against multiple sources. Once this agreement was obtained, I created an Excel-based tool that would draw information from each chosen source and consolidate it in a way that facilitated material balancing decisions. Below is a snapshot explanation of what was eventually termed the "Balancing Tool".

	Main Part # Description				31-Dec Sat	1-Jan Sun	2-Jan Mon	3-Jan Tue	4-Jan Ved	5-Jan Thu	6-Jan Fri
AFC	XXXXX	NOH	250	Demand (from FSS)			2,500	2,500	2,500	2,500	2,500
	% Options 10%	SLC	23000	Demand Adjustment							
AUSTIN	Shortage	Yard Inv	7,500	AVL	25,478	25,478	25,478	22,978	20,478	17,978	15,478
	Tool	B/L	300	Options Adjustment							
	Comment:	AVL	30,450	Delivery (Tracking File)							
	Routing	Opt BL	100	Delivery Adj. (w/ Opt)							
	Analayst	Total AVL	30,450	Delivery Adj. (no Opt)							
	Comment	Late Supply	0	DELTA	25,478	25,478	22,978	20,478	17,978	15,478	12,978
	Pending Transfer(s):			DSI			9.2	8.2	7.2	6.2	5.2
NFC	XXXXX	NOH	600	Demand (from FSS)			5,000	5,000	5,000	5,000	5,000
	% Options 10%	SLC	10000	Demand Adjustment							
Nashville	Shortage	Yard Inv	18,000	AVL	-1,838	-1,838	-1,838	-6,838	-11,838	-16,838	-21,838
	Tool	B/L	16000	Options Adjustment							
	Comment:	AVL	13,000	Delivery (Tracking File)							
	Routing	Opt BL	15,000	Delivery Adj. (w/ Opt)							
	Analayst	Total AVL	13,000	Delivery Adj. (no Opt)							
	Comment	Late Supply	0	DELTA	-1,838	-1,838	-6,838	-11,838	-16,838	-21,838	-26,838
	Pending Transfer(s):			DSI			-1.4	-2.4	-3.4	-4.4	-5.4
RFC	XXXXX	NOH	25	Demand (from FSS)			850	850	850	850	850
	% Options 10%	SLC	14,000	Demand Adjustment							
RFC	Shortage	Yard Inv	0	AVL	14,000	14,000	14,000	13,150	12,300	11,450	10,600
	Tool	B/L	25	Options Adjustment							
	Comment:	AVL	14,000	Delivery (Tracking File)							
	Routing	Opt BL		Delivery Adj. (w/ Opt)							
	Analayst	Total AVL	14,000	Delivery Adj. (no Opt)							
	Comment	Late Supply	0	DELTA	14,000	14,000	13,150	12,300	11,450	10,600	9,750
	Pending Transfer(s):			DSI			15.5	14.5	13.5	12.5	11.5

Figure 15. The "Balancing Tool" created to facilitate material balancing decisions during the Dynamic Replenishment pilot.

Model Illustration and Explanation

As previously stated, the primary objectives of this tool were to 1) facilitate quick identification of potential shortages and imbalances and 2) to provide a platform for "what-if" scenarios such that the user could enter information about planned transfers and diversions, and quickly understand the potential outcomes. The below diagram illustrates the critical elements of the tool.

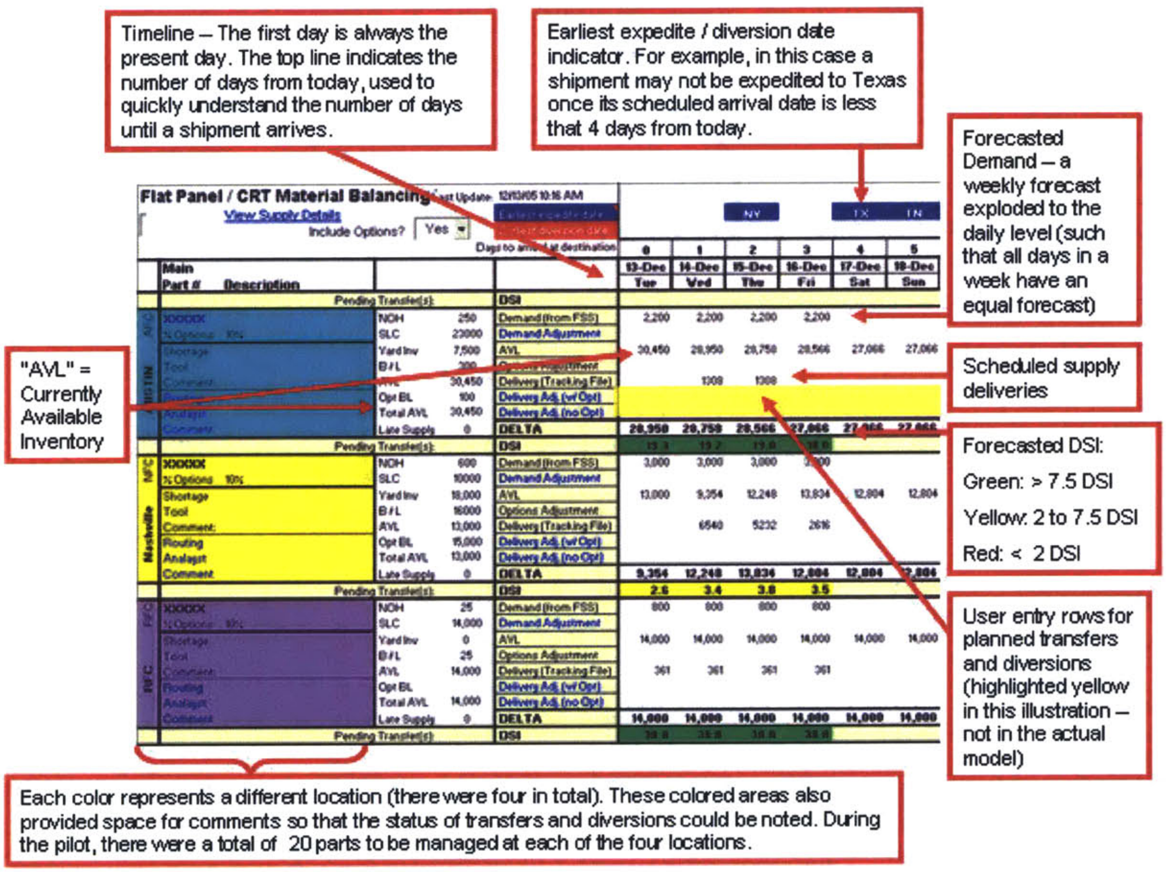


Figure 16. Critical elements of the material balancing model.

Use of the Model

In order to fully understand the daily use of this model, the best method is to illustrate both an example of a required transfer as well as of a necessary diversion.

<u>Transfer Example</u>

The following snapshot of the Material Balancing Tool (with the present date being Dec. 13) is an example of a situation in which a transfer is clearly warranted. Following is an explanation of the reasoning and actions that would be taken to alleviate the situation.

Flat Panel / CRT Material Balancing	Last Update: 12/13/05 10:16 AM													
	View Supply Details			Earliest expedite date			NV		TX	TN				
	Include Options? Yes			Earliest diversion date										NV
				Days to arrival at destination	0	1	2	3	4	5	6	7	8	9
	Main Part # Description				13-Dec Tue	14-Dec Wed	15-Dec Thu	16-Dec Fri	17-Dec Sat	18-Dec Sun	19-Dec Mon	20-Dec Tue	21-Dec Wed	22-Dec Thu
AFC AUSTIN	XXXXX	NOH	350	Demand (from FSS)	1,500	1,500	1,500	1,500			1,000	1,000	1,000	1,000
	% Options 10%	SLC	2000	Demand Adjustment										
	Shortage	Yard Inv	3,000	AVL	5,150	3,650	2,150	650	-850	-850	-850	-1,850	-1,550	3,450
	Tool	B/L	200	Options Adjustment										
	Comment:	AVL	5,150	Delivery (Tracking File)								1300	6000	
	Routing	Opt BL	100	Delivery Adj. (w/ Opt)										
	Analayst	Total AVL	5,150	Delivery Adj. (no Opt)										
	Comment	Late Supply	0	DELTA	3,650	2,150	650	-850	-850	-850	-1,850	-1,550	3,450	2,450
	Pending Transfer(s):			DSI	2.4	1.4	0.4	-0.6			-1.9	-1.6	3.5	2.5
NFC Nashville	XXXXX	NOH	700	Demand (from FSS)	3,800	3,800	3,800	3,800			2,000	2,000	2,000	2,000
	% Options 10%	SLC	13000	Demand Adjustment										
	Shortage	Yard Inv	30,000	AVL	27,700	23,900	24,600	20,800	17,000	17,000	17,000	15,000	18,000	20,500
	Tool	B/L	16000	Options Adjustment										
	Comment:	AVL	27,700	Delivery (Tracking File)		4500						5000	4500	
	Routing	Opt BL	15,500	Delivery Adj. (w/ Opt)										
	Analayst	Total AVL	27,700	Delivery Adj. (no Opt)										
	Comment	Late Supply	0	DELTA	23,900	24,600	20,800	17,000	17,000	17,000	15,000	18,000	20,500	18,500
	Pending Transfer(s):			DSI	6.3	6.5	5.5	4.5			7.5	9.0	10.3	9.3
RFC RFC	XXXXX	NOH	25	Demand (from FSS)	1,100	1,100	1,100	1,100			800	800	800	800
	% Options 10%	SLC	8,000	Demand Adjustment										
	Shortage	Yard Inv	0	AVL	8,000	6,900	7,100	6,000	4,900	4,900	4,900	4,100	3,300	2,500
	Tool	B/L	25	Options Adjustment										
	Comment:	AVL	8,000	Delivery (Tracking File)		1300								
	Routing	Opt BL		Delivery Adj. (w/ Opt)										
	Analayst	Total AVL	8,000	Delivery Adj. (no Opt)										
	Comment	Late Supply	0	DELTA	6,900	7,100	6,000	4,900	4,900	4,900	4,100	3,300	2,500	1,700
	Pending Transfer(s):			DSI	6.3	6.5	5.5	4.5			5.1	4.1	3.1	2.1

Figure 17. A depiction of a situation requiring a transfer in the Material Balancing Tool.

Problem Identification and Alleviation

1) A likely part shortage is identified by the red DSI levels in Austin from Dec. 14 to Dec. 20. Austin will run short of the part starting on Dec. 16.
2) The routing analyst verifies that all inventory information is correct and no deviations exist for this part.
3) The routing analyst determines what material balancing action to take:
    a. Although there is a shipment of 4500 pieces to Nashville and also one of 1300 to Reno on the way, these shipments are beyond their diversion timeframes (they have passed the US port and are already on the rail, so cannot be diverted).
    b. No parts are being shipped to Austin during the shortage timeframe, so an expedite is not an option.
    c. The remaining option is to transfer material from another factory that has available supply.
4) The peak shortage amount (on Dec. 19) is forecasted to be 1,850 pieces, so that is the minimum amount that should be transferred from another factory.
5) Nashville currently has 23,900 pieces of excess supply (from the "Delta" line) while Reno only has 6,900. Also, during this time of year, trucks are highly difficult to schedule out of Reno as weather conditions are bad and backhauls out of Reno are scarce. Therefore, the transfer will be initiated out of Nashville. The transit time from Nashville to Austin is about two days so the supply should arrive in time (by Dec. 16).
6) The routing analyst determines that the truck capacity for this part is 1500 per truck, so a shipment of 3000 is scheduled (in excess of the required 1,850 pieces, but this is ok since Nashville and Austin remain out of balance in the long term. On Dec. 22, Nashville will have 9.3 DSI while Austin will have only 2.5, so it makes sense to fill out the two truckloads in order to further balance the sites).

7) The routing analyst logs the request in the Material Balancing Tool and submits an official request to the logistics organization through an online application and monitors its progress through direct communication and emails.

The following depicts the Material Balancing Tool after the routing analyst has logged the plans. Refer to the "Delivery Adjustment" lines for Austin and Nashville, noting that a negative inventory adjustment has been made to Nashville and a positive one to Austin (three days in the future).

Flat Panel / CRT Material Balancing Last Update: 12/13/05 10:16 AM

View Supply Details

Include Options? Yes

Earliest expedite date

Earliest diversion date

Site	Main Part # / Description			Days to arrival at destination	0	1	2	3	4	5	6	7	8	9
							NV		TX	TN				NY
					13-Dec Tue	14-Dec Wed	15-Dec Thu	16-Dec Fri	17-Dec Sat	18-Dec Sun	19-Dec Mon	20-Dec Tue	21-Dec Wed	22-Dec Thu
AFC AUSTIN	XXXXX	NOH	350	Demand (from FSS)	1,500	1,500	1,500	1,500			1,000	1,000	1,000	1,000
	% Options 10%	SLC	2000	Demand Adjustment										
	Shortage	Yard Inv	3,000	AVL	5,150	3,650	2,150	650	2,150	2,150	2,150	1,150	1,450	6,450
	Tool	B/L	200	Options Adjustment										
	Comment:	AVL	5,150	Delivery (Tracking File)								1300	6000	
	Routing	Opt BL	100	Delivery Adj. (w/ Opt)				3000						
	Analayst	Total AVL	5,150	Delivery Adj. (no Opt)										
	Comment	Late Supply	0	DELTA	3,650	2,150	650	2,150	2,150	2,150	1,150	1,450	6,450	5,450
	Pending Transfer(s):			DSI	2.4	1.4	0.4	1.4			1.2	1.5	6.5	5.5
NFC Nashville	XXXXX	NOH	700	Demand (from FSS)	3,800	3,800	3,800	3,800			2,000	2,000	2,000	2,000
	% Options 10%	SLC	13000	Demand Adjustment										
	Shortage	Yard Inv	30,000	AVL	27,700	20,900	21,600	17,800	14,000	14,000	14,000	12,000	15,000	17,500
	Tool	B/L	16000	Options Adjustment										
	Comment:	AVL	27,700	Delivery (Tracking File)		4500						5000	4500	
	Routing	Opt BL	15,500	Delivery Adj. (w/ Opt)	-3000									
	Analayst	Total AVL	27,700	Delivery Adj. (no Opt)										
	Comment	Late Supply	0	DELTA	20,900	21,600	17,800	14,000	14,000	14,000	12,000	15,000	17,500	15,500
	Pending Transfer(s):			DSI	5.5	5.7	4.7	3.7			6.0	7.5	8.8	7.8
RFC	XXXXX	NOH	25	Demand (from FSS)	1,100	1,100	1,100	1,100			800	800	800	800
	% Options 10%	SLC	8,000	Demand Adjustment										
	Shortage	Yard Inv	0	AVL	8,000	6,900	7,100	6,000	4,900	4,900	4,900	4,100	3,300	2,500
	Tool	B/L	25	Options Adjustment										
	Comment:	AVL	8,000	Delivery (Tracking File)		1300								
	Routing	Opt BL		Delivery Adj. (w/ Opt)										
	Analayst	Total AVL	8,000	Delivery Adj. (no Opt)										
	Comment	Late Supply	0	DELTA	6,900	7,100	6,000	4,900	4,900	4,900	4,100	3,300	2,500	1,700
	Pending Transfer(s):			DSI	6.3	6.5	5.5	4.5			5.1	4.1	3.1	2.1

Figure 18. The Material Balancing Model after a required transfer has been logged.

As a result of the transfer, all sites are relatively balanced by Dec. 22, and the routing analyst has reached her objective.

<u>Diversion Example</u>

The following snapshot of the Material Balancing Tool depicts the *same model* on the *same day* as the previous transfer example. However, the routing analyst has moved on to reviewing a later timeframe – the *diversion* timeframe for the same part. All transfers have been logged on the earlier dates, so the forecasted inventory levels in this more distant timeframe should be correct.

Flat Panel / CRT Material Balancing Last Update: 12/13/05 10:16 AM

View Supply Details

Include Options? Yes

Earliest expedite date

Earliest diversion date

TN (above 14 / 27-Dec) TX, NCO (above 15 / 28-Dec)

	Main Part # Description			Days to arrival at destination	10	11	12	13	14	15	16	17	18	19	20
					23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec	1-Jan	2-Jan
					Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon
AFC	XXXXX	NOH	350	Demand (from FSS)	1,000			900	900	900	900	900			1,000
	% Options 10%	SLC	2000	Demand Adjustment											
AUSTIN	Shortage	Yard Inv	3,000	AVL	5,450	4,450	4,450	4,450	3,550	8,650	10,050	9,150	8,250	8,250	8,250
	Tool	B/L	200	Options Adjustment											
	Comment:	AVL	5,150	Delivery (Tracking File)					6000	2300					1100
	Routing	Opt BL	100	Delivery Adj. (w/ Opt)											
	Analayst	Total AVL	5,150	Delivery Adj. (no Opt)											
	Comment	Late Supply	0	DELTA	4,450	4,450	4,450	3,550	8,650	10,050	9,150	8,250	8,250	8,250	8,350
	Pending Transfer(s):			DSI	4.5			3.9	9.6	11.2	10.2	9.2			8.4
NFC	XXXXX	NOH	700	Demand (from FSS)	2,000			2,400	2,400	2,400	2,400	2,400			3,400
	% Options 10%	SLC	13000	Demand Adjustment											
Nashville	Shortage	Yard Inv	30,000	AVL	15,500	13,500	13,500	13,500	11,100	14,500	12,100	9,700	8,600	8,600	8,600
	Tool	B/L	16000	Options Adjustment											
	Comment:	AVL	27,700	Delivery (Tracking File)					5800			1300			4300
	Routing	Opt BL	15,500	Delivery Adj. (w/ Opt)											
	Analayst	Total AVL	27,700	Delivery Adj. (no Opt)											
	Comment	Late Supply	0	DELTA	13,500	13,500	13,500	11,100	14,500	12,100	9,700	8,600	8,600	8,600	9,500
	Pending Transfer(s):			DSI	6.8			4.6	6.0	5.0	4.0	3.6			2.8
RFC	XXXXX	NOH	25	Demand (from FSS)	800			250	250	250	250	250			400
	% Options 10%	SLC	8,000	Demand Adjustment											
RFC	Shortage	Yard Inv	0	AVL	1,700	900	900	900	650	400	150	-100	-350	-350	-350
	Tool	B/L	25	Options Adjustment											
	Comment:	AVL	8,000	Delivery (Tracking File)											
	Routing	Opt BL		Delivery Adj. (w/ Opt)											
	Analayst	Total AVL	8,000	Delivery Adj. (no Opt)											
	Comment	Late Supply	0	DELTA	900	900	900	650	400	150	-100	-350	-350	-350	-750
	Pending Transfer(s):			DSI	1.1			2.6	1.6	0.6	-0.4	-1.4			-1.9

Figure 19. A depiction of a situation requiring a diversion in the Material Balancing Tool.

Problem Identification and Alleviation

1) A likely part shortage is identified by the red DSI levels in Reno from Dec. 27 to Jan. 2.
2) The routing analyst verifies that all inventory information is correct and no deviations exist for this part.
3) In this timeframe, transfers are not a consideration. This is because transfers are a last-minute option (within a five-day time horizon). Up until that point, the routing analyst will either wait to see if demand levels shift or execute a diversion where possible. Also, expedites will have no impact on the overall supply levels in this time horizon as they only speed up the arrival of supply that is already coming. Therefore, only diversions are considered when reviewing DSI levels in this timeframe.
4) The peak shortage amount (on Jan. 2) is forecasted to be 750 pieces, so that is the minimum amount that should be diverted from another factory.
5) The best location from which to divert is Austin, since it has the most DSI and has a large shipment (2300 pieces) arriving within its diversion timeframe (note that the red cells above the time horizon indicate that the latest diversion point for supply en-route to Nashville is 14 days from today, and for Austin and North Carolina, 15 days). However, the routing analyst checks the arrival date of the Austin shipment (of 2300 pieces) in the ocean carrier's database and finds that it is already at the US port and has passed the 48-hour pre-port notification deadline. As a result, material must be routed from the shipment of 1300 that is en-route to Nashville. The routing analyst verifies that this material has not missed the notification deadline.
6) The routing analyst researches the supplier that owns the Nashville shipment and verifies that it is a single container.
7) The routing analyst sends an email request to the supplier, who in turn sends a request to the carrier for the diversion. Four hours later, the diversion is approved and is logged in the Material Balancing Tool.

The following depicts the Material Balancing Tool after the routing analyst has logged the plans. Refer to the "Delivery Adjustment" lines for Nashville and Reno, noting that a negative inventory adjustment has been made to Nashville and a positive one to Reno. Also note that the delivery will arrive in Reno *four days earlier* because the delivery time from the US port to Reno is four days shorter than that to Nashville.

Flat Panel / CRT Material Balancing Last Update: 12/13/05 10:16 AM
View Supply Details
Include Options? Yes
Earliest expedite date
Earliest diversion date
TN TX, NCO

	Main Part # Description				10	11	12	13	14	15	16	17	18	19	20
				Days to arrival at destination	23-Dec Fri	24-Dec Sat	25-Dec Sun	26-Dec Mon	27-Dec Tue	28-Dec Ved	29-Dec Thu	30-Dec Fri	31-Dec Sat	1-Jan Sun	2-Jan Mon
AFC	XXXXX	NOH	350	Demand (from FSS)	1,000			900	900	900	900	900			1,000
AFC	% Options 10%	SLC	2000	Demand Adjustment											
AUSTIN	Shortage	Yard Inv	3,000	AVL	5,450	4,450	4,450	4,450	3,550	8,650	10,050	9,150	8,250	8,250	8,250
AUSTIN	Tool	B/L	200	Options Adjustment											
AUSTIN	Comment:	AVL	5,150	Delivery (Tracking File)					6000	2300					1100
AUSTIN	Routing	Opt BL	100	Delivery Adj. (w/ Opt)											
AUSTIN	Analayst	Total AVL	5,150	Delivery Adj. (no Opt)											
AUSTIN	Comment	Late Supply	0	**DELTA**	**4,450**	**4,450**	**4,450**	**3,550**	**8,650**	**10,050**	**9,150**	**8,250**	**8,250**	**8,250**	**8,350**
	Pending Transfer(s):			**DSI**	**4.5**			**3.9**	**9.6**	**11.2**	**10.2**	**9.2**			**8.4**
NFC	XXXXX	NOH	700	Demand (from FSS)	2,000			2,400	2,400	2,400	2,400	2,400			3,400
NFC	% Options 10%	SLC	13000	Demand Adjustment											
Nashville	Shortage	Yard Inv	30,000	AVL	15,500	13,500	13,500	13,500	11,100	14,500	12,100	9,700	7,300	7,300	7,300
Nashville	Tool	B/L	16000	Options Adjustment											
Nashville	Comment:	AVL	27,700	Delivery (Tracking File)					5800			1300			4300
Nashville	Routing	Opt BL	15,500	Delivery Adj. (w/ Opt)								-1300			
Nashville	Analayst	Total AVL	27,700	Delivery Adj. (no Opt)											
Nashville	Comment	Late Supply	0	**DELTA**	**13,500**	**13,500**	**13,500**	**11,100**	**14,500**	**12,100**	**9,700**	**7,300**	**7,300**	**7,300**	**8,200**
	Pending Transfer(s):			**DSI**	**6.8**			**4.6**	**6.0**	**5.0**	**4.0**	**3.0**			**2.4**
RFC	XXXXX	NOH	25	Demand (from FSS)	800			250	250	250	250	250			400
RFC	% Options 10%	SLC	8,000	Demand Adjustment											
RFC	Shortage	Yard Inv	0	AVL	1,700	900	900	900	1,950	1,700	1,450	1,200	950	950	950
RFC	Tool	B/L	25	Options Adjustment											
RFC	Comment:	AVL	8,000	Delivery (Tracking File)											
RFC	Routing	Opt BL		Delivery Adj. (w/ Opt)				1300							
RFC	Analayst	Total AVL	8,000	Delivery Adj. (no Opt)											
RFC	Comment	Late Supply	0	**DELTA**	**900**	**900**	**900**	**1,950**	**1,700**	**1,450**	**1,200**	**950**	**950**	**950**	**550**
	Pending Transfer(s):			**DSI**	**1.1**			**7.8**	**6.8**	**5.8**	**4.8**	**3.8**			**1.4**

Figure 20. The Material Balancing Model after a required diversion has been logged.

As a result of the diversion, Reno will no longer run short. However, one may note that a second potential diversion exists on Jan. 2 from Austin or Nashville to Reno. The routing analyst would again follow a similar process to make the decision regarding this diversion.

The Decision Algorithm

Upon repeating these decisions multiple times per week, it became apparent that there was a flow of logic behind them. One's thought, then, is that perhaps these types of decisions may one day be automated. Dell's supply chain management did enquire about this, and the response is that it is absolutely possible, but a stronger foundation of information will be required. In the processes described above, only a brief bullet was dedicated to the "validation of information". However, this step would often consume 50-80% of the time required to execute a single transfer or diversion. Automation of these types of decisions will not be possible until all relevant information is readily available. See section 6.1 for further discussion of informational requirements, particularly as part of integrated IT systems.

Contemplation of this decision algorithm also leads one to consideration of the potential for the *optimization* of material allocation to multiple locations. Although the Dynamic Replenishment project was focused on implementation and organizational aspects of the problem, a discussion of related research on this type of optimization will prove relevant. As Dell and other companies conduct similar projects, research such as this should serve as the long term vision of what will one day be possible given the right foundational systems. The following section offers a brief review of some of the literature that exists in this area and the gaps in assumptions that exist between their respective theoretical situations and Dell's real-world situation.

5.1.3 Literature Review: Multi-Location Inventory Allocation

As discussed in Section 4, the fundamental effect of the Dynamic Replenishment Project was to effectively *postpone* the geographical allocation of product to specific factories as it traveled from Asia to the US. This concept is analogous to others in the inventory management arena, such as the postponement of product differentiation. In management science literature, these types of ideas are exchanged under terminological umbrellas such as *inventory pooling* or *inventory centralization*. The basic idea behind this literature is that, when a product has long lead times, high holding costs, and multiple final destinations, there are benefits to ordering in a centralized manner rather than separately for each location. With regard to the Dynamic Replenishment Project, this "centralized ordering" would be analogous to regularly ordering parts for the entire Americas region without designation of final location until arrival at the US port. The following is a brief review of key published works in this area as well as some discussion of the differences between the literature assumptions and Dell's situation.

In 1981, Eppen and Schrage (12) published "Centralized Ordering Policies in a Multi-Warehouse System with Lead Times and Random Demand". They discuss the idea of the introduction of a "depot", which holds no inventory, but facilitates centralized ordering policies and postponement of the designation of final destination. Given certain system parameters (such as lead times, number of warehouses, and average demand) and costs (inventory holding costs, backorder costs, and order cost), an optimized ordering policy can be determined such that costs are minimized. These costs will be less in a system with an inventory depot because of inventory "risk pooling". This is the idea that the random fluctuations of demand at each individual location are, in total, higher than the *aggregate* fluctuation of the *total demand* (referred to by Eppen and Schrage as "statistical economies of scale"). This suggests that less buffer stock (stock held in excess of forecasted demand in order to compensate for random fluctuations) is required when inventory is ordered in aggregate rather than for each individual location. Note that, since these fluctuations accumulate over time, this effect is amplified as a product's lead time becomes longer. The idea of risk pooling is important to Dell for two reasons: 1) Dell's product lead times have increased due to the migration of its supply base to Asia and 2) Inventory holding costs are very high due to rapid obsolescence of parts in the electronics industry. Inventory risk pooling will help Dell to mitigate the impact of demand fluctuations throughout product lead times and reduce the amount of stock that must be held at risk of obsolescence.

Although it is clear that the fundamental ideas presented by Eppen and Schrage are important ones for Dell, there are a number of assumptions made which restrict the direct applicability of those ideas to Dell's real-world situation. Those assumptions include:

- The "Allocation Assumption": An assumption that for every period an allocation (at the depot) may be made such that the probability of running out at each warehouse is the same as in the next period (16). (This assumption is a pervasive one throughout much of the inventory pooling literature, and is most true in the case of low covariance of demand and fewer numbers of warehouses.)

- Demand is equal in all time periods.
- Demands for individual locations and between time periods are uncorrelated.
- Demand is normally distributed.
- Every location has the same inventory holding and backorder costs.
- A specific ordering policy (for example, order up to a certain amount each period) is assumed.
- Demand is continuous.
- The time horizon is infinite.

Since the publishing of Eppen and Schrage's works, researchers have made progress in eliminating some of these assumptions in search of a more realistic model for inventory ordering. In 1984, Federgruen and Zipkin (13) published a model based on dynamic programming that provided significantly more flexibility in assumptions than the Eppen and Schrage paper. The principle of *myopic allocation* is used, suggesting that an optimal ordering solution is determined one period at a time that will minimize costs in the next period without regard to costs in subsequent periods (13). The broadened scope of the paper and more robust dynamic programming solution allow for the relaxation of a number of Eppen and Schrage's assumptions, including:

- Demand no longer need be assumed to be normally distributed.
- Holding and backorder costs may be different across locations.
- The time horizon may be finite.
- Ordering policy is not pre-determined, but rather arises according to "the actual nature of the ordering costs" (13).

Further research has focused on alleviating specific assumptions, including that of Erkip, Hausman, and Nahmias in 1990 (14), which allowed for demand correlations (both across locations and between time periods), and that of Dogru, de Kok, and can Houtum in 2004 (15), which allowed for discrete customer demand. (Note that these works did not build directly on the work of Federgruen and Zipkin, meaning that some restrictions were put back in place in order to relax others. For example, the work of Erkip, Hausman, and Nahmias was based on a specific ordering policy – an order-up-to policy – even though Federgruen and Zipkin had relaxed the assumption in their work.)

The work that has been done to make these theoretical models applicable to today's complex situations has brought the world of academia one step closer to Dell's. The research has made clear the fact that Dell can benefit from a centralized ordering policy by reducing stockouts, holding costs, and obsolescence. However, the day when Dell may implement one of these algorithms autonomously for routing decisions is not yet here. This is due to gaps between the current model assumptions and Dell's reality, as well as the fact that Dell is not yet capable of consistently providing the significant amounts of data needed to fuel such a model. Supposing Dell were able to provide the necessary data, the following are some of the gaps that remain to be closed in the creation of an applicable inventory ordering model for Dell:

- The allocation assumption – This assumption will distort model outcomes as Dell adds more locations and as covariance of demand increases. Both of these events are likely to happen as Dell serves more customers and expands product portfolios.

- Site-to-site transfers – An applicable model will need to allow for these transfers.

- Expedites – Dell executes expedites, either from Asia to the US (by plane) or within the US (by truck). An accurate model will have to take this into account.

- Ordering exceptions – In a fast industry such as Dell's, products are discontinued rapidly. When products are discontinued, a large "last time buy" order is placed. This is one example of an exception to the normal ordering process. Current ordering models would not be able to accommodate these types of exceptions.

These are just a few examples of gaps that exist, as Dell's environment presents many exceptional challenges which are not yet incorporated into academic literature. However, I do not intend to suggest that the solution for Dell is to derive the "ultimate" ordering algorithm, capable of handling every possible situation. The sophisticated solution for Dell will involve understanding the implications of the collective research in this area and how various elements of it can be put together in order to derive a proprietary and practical solution that will work specifically for Dell. Models such as these also not only serve to help with periodic ordering decisions, but provide a mechanism for sensitivity analysis. Dell might utilize them in order to determine the cost impact of adding a new location or cost savings from lead time reductions, for example. This is powerful research with powerful implications for companies like Dell, and completion of the Dynamic Replenishment Project has the potential to serve as a stepping stone toward achieving such optimal inventory policies. It is advisable that Dell remain alert to new opportunities for gains of this nature as its business grows and evolves.

5.2 Pilot Execution: Improving the Processes

Recall that in Section Three, material balancing processes were described as two independent processes: one for transfers and expedites and one for diversions. This was primarily because transfers and expedites (which occur within days of identification) were typically identified by US-based team members on an ad-hoc basis, whereas diversions (which require regular proactive monitoring of supply that is weeks from delivery) were identified during a regularly scheduled meeting between BPs and suppliers. There existed a critical flaw in this separation of responsibility, since diversion decisions are highly dependent on transfer decisions. For example, if a factory is projected to run short on a part within three days and remain short for an extended period of time, a commodity team member will almost surely initiate a site-to-site transfer of material and the BP will almost surely initiate a diversion request for supply that is traveling on the ocean at the time. The result will be that the site that is currently short on the part will have a massive excess of the part within a couple of weeks. This problem occurred twice through the course of two months of the pilot, with one of the instances incurring costs to send the material *back* to the site from which it was re-routed. In light of this, our first goal was to merge the separate processes into one. The new process would reflect their dependence, requiring that all transfer and expedite decisions be completed *before* and diversion decisions were made. This ensured that fewer unnecessary diversions would occur.

Based on this and other goals, the following became the new material balancing process.

<u>New Material Balancing Process: Transfers, Expedites, and Diversions</u>

1) *All parts are reviewed for material imbalances* – This occurs twice a week.

2) *Transfers and expedites are initiated* – Since ownership now lies clearly with the routing analyst, transfers and expedites are immediately initiated.

3) *All parts are reviewed for potential diversions* – Once all transfers and expedites have been documented, the diversion decisions regarding the routing of material that is still en-route on the ocean may be made. *This was the most critical element of the pilot.* As discussed, the basic goal of the Dynamic Replenishment project was to establish a more *proactive* process whereby material would be routed to the correct location at the last possible moment, avoiding the high cost of site-to-site material transfers. The key to the pilot was that Dell now had a role focused on these proactive measures, whereas before, no single role was focused on this.

4) *Transfer, expedite, and diversion decisions are communicated* – All material routing actions are documented electronically in a public location with regular status updates.

Appendix C illustrates a diagram of the material balancing process before and after the pilot, highlighting the roles of each key participant. Much of the overlap in responsibility is eliminated with the new process. Also, note that one of the roles – the RSM – is completely removed from the process, which aligned well with management's desire to establish the RSM role as a more strategic one.

5.3 Pilot Execution: Implementation and Experience

These improved tools and processes were implemented starting in mid-September 2005, with preparation beginning in early September. First, complete buy-in on the new tools and processes was obtained from the commodity team and all involved managers. (This step was made much easier by the fact that the commodity team and all relevant managers had been included in the project development process from the beginning.) Next, I conducted training sessions for those who required them on the new tools, and I received intensive on-the-job training from the commodity team on material balancing procedures. After about three weeks of working through the new system and learning the new tools, the team settled into the new processes quite well. However, the two-month duration of the pilot was by no means simple and the experience was challenging and educating.

The Pilot Experience

Few company interns are offered the opportunity to perform a critical daily function within an organization, let alone to perform one in the middle of one of the company's most critical organizations (Logistics, in this case) for one of its most important commodities. The experience is one for which I am highly grateful and will certainly leverage in the solution of any logistics problem I encounter in the future. In order to provide some perspective to the reader as to the nature of my pilot experience, I offer a bit of supplemental information about the daily tasks which were involved in the pilot.

Daily Life as a Routing Analyst

Often – at the beginning of the week – it was typical to find that a number of the demand assumptions we had made the previous week had changed. Perhaps a large order had "dropped" over the weekend, causing a particular site to run short on a part with little advance notice. Perhaps demand levels had shifted dramatically because of a new website promotion. Whatever the reason, the first task was to address those emergency issues which had arisen. This involved rapid research of current inventory and supply information, and the initiation of any necessary material transfers. Next, all information in the Material Balancing Tool would be updated in preparation for the weekly material balancing review with the commodity team.

During the commodity team meeting, team members voiced their concerns regarding particular parts and corrected information for which our assumptions were incorrect (typically demand forecast information). This discussion resulted in a multitude of actions, all of which typically required validation of information (demand, supply, inventory) for a set of parts and various actions to be taken to alleviate the imbalanced material situations (e.g. transfers, part deviations).

After the commodity team meeting was conducted and resulting actions had been executed, more emphasis would be placed on *proactive* diversions. These were the actions from which the success of the pilot would be derived, and more and more focus was placed on them as we became more proficient at managing the emergency situations. Project management tasks would also be performed, such as progress reports and the weekly updating of success indicators (to be reviewed in Section 5.4).

Throughout each week, as these tasks were performed, we carefully tracked information that would ultimately tell us if we had been successful. The following section details those results as well as the criteria against which they were compared.

5.4 Pilot Results

Before the pilot began, clear success criteria had been determined in order to facilitate a true measurement of success. These pilot success indicators were directly linked to the goals for cost savings and organizational benefits as outlined in Section Four. Upon completion of the pilot, it was evaluated against these criteria. The following is a review of those criteria and the final measured success according to those criteria.

Success Criteria

The following is a summary of specific goals that were to be met during the pilot in these areas:

- Reduction in spending on transfers and expedites in accordance with the project cost savings estimates (as outlined in section 4.1.1). For the pilot, these savings would be about 28% of the total anticipated project savings, since that is the amount of expedite spend that was historically associated with the piloted commodity.

- Significant reduction in factory shortages of the piloted commodity. This goal was not quantified, as there existed a number of exogenous factors which would increase or decrease part shortages, and it proved highly difficult to attribute shortages to a direct cause. We hoped that, after the fact, we could deduct other known factors and attempt to isolate shortage reductions that were attributable to the Dynamic Replenishment Project.

- Organizational improvements, including clearer roles, improvement in work / life balance, and elimination of redundant efforts. These results were to be measured through interviews with the pilot commodity team members upon completion of the project.

The cost savings success indicators were tracked beginning in the third week of the pilot (after a two week training period) and reported weekly to the team and managers. A bi-weekly report was also sent to higher level managers indicating progress and potential roadblocks where those managers could provide assistance. (Throughout the project, these frequent communications with managers proved invaluable in removing roadblocks and building support).

Results
As is true of many project pilots, we faced a challenge in determining the true impact of our actions amidst a number of exogenous factors. For example, the pilot was conducted during a downturn in demand levels, meaning that part shortages would inherently decrease, regardless of the actions we took. Also, a diversion mistake that had been made before the pilot began resulted in significant material balancing spending during two weeks of the pilot, drastically reducing our apparent success in lowering logistics costs. In order to separate the effects of these factors from our project's effects, we tracked them carefully. A clear understanding of *when* demand decreased could help us understand whether or not our project's improvements would be confounded with that decrease (hopefully, they would occur at different times and be separable). Also, we tracked the costs and reasons for every single site-to-site transfer that was executed over the course of the pilot. In this manner, we could separate those transfers that were a result of decisions over which we had no control (e.g. decisions that had been made before the pilot began).

The following are some charts that were presented as part of a final project review, along with brief explanations as to how the exogenous factors were mitigated.

Logistics Cost Reduction

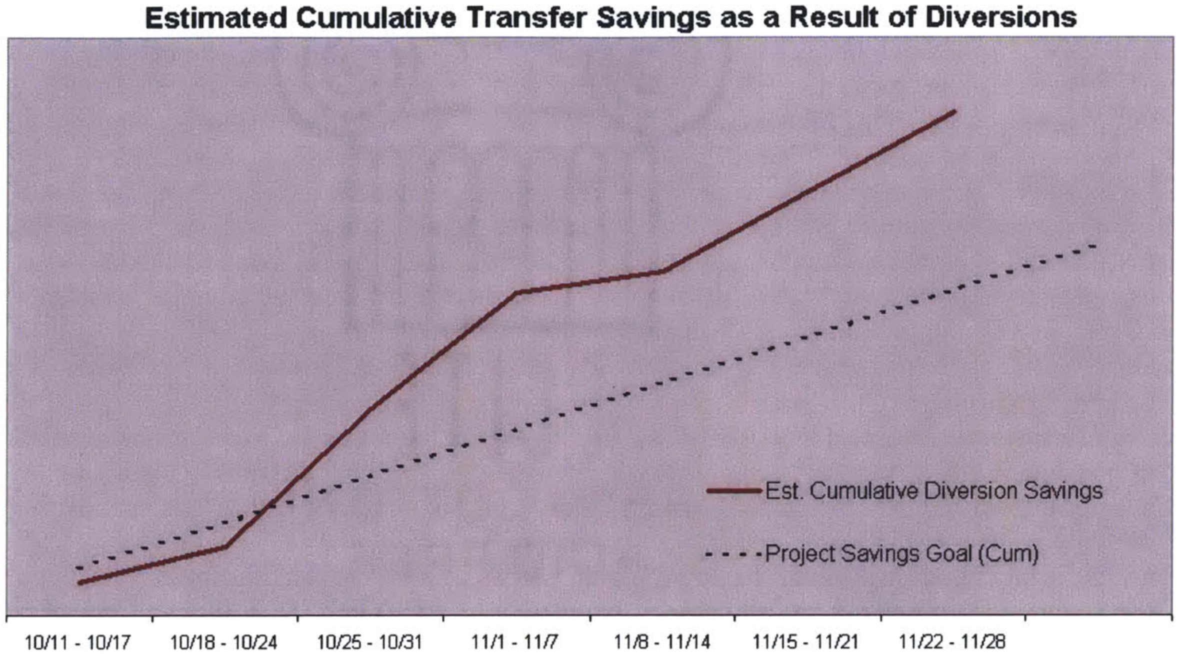


Figure 21. Cumulative weekly estimated savings as a result of diversions executed during the pilot.

Each time a diversion was conducted, an assumption was made that it was likely that a corresponding site-to-site transfer had been avoided. For example, if 10 containers of a part were diverted from Austin to Nashville (before arrival at the US port), and the cost to transfer a single truckload of parts from Austin to Nashville would have been $1000 (note that this does not reflect actual cost), then the total savings would be $10,000 (assuming trucks carry the same amount of parts as ocean containers). It would not be prudent to assume that *all* diversions result in transfer avoidance, so only a conservative 50% were assumed to have had this impact (based on experience during the pilot, at least four of every five diversions did result in transfer avoidance, so 50% was conservative relative to this estimate of 80%). Given these assumptions, the pilot was well on track toward the cost savings goals that had been established.

Part Shortage Reduction

As previously mentioned, a decline in overall demand caused a reduction in part shortages for most parts at Dell. However, this decline occurred long *before* the pilot began, suggesting that the dramatic reduction indicated below (of 50%) was indeed due to actions taken during the pilot. Below is a chart reflecting this improvement for the commodity that was piloted.

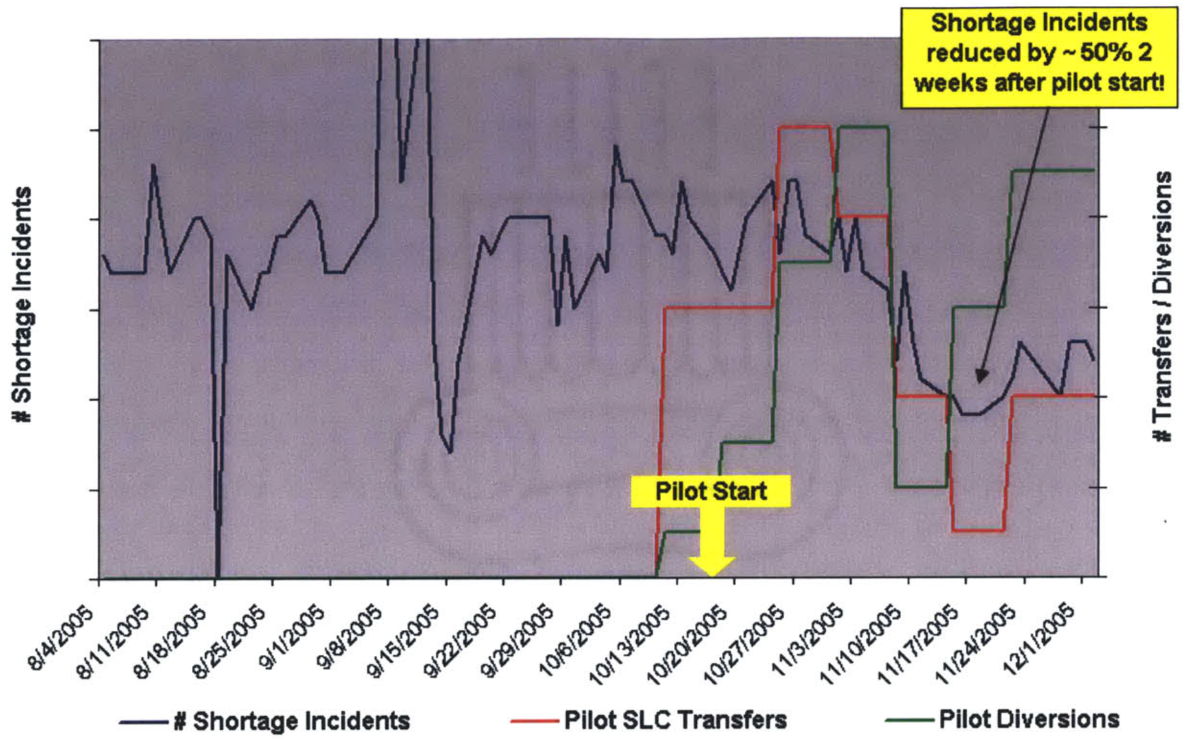


Figure 22. Reduction in Commodity 1 shortage incidents after the start of the Dynamic Replenishment pilot.

Organizational Improvements

Improvements to the organization were, for the most part, measured through interviews and surveys. Sample questions which were asked during these interviews included:

- Do you believe that the routing analyst role should be kept?
- How has the addition of the routing analyst role improved or hindered your job?
- Do you believe that material balancing roles were clarified by the pilot?

Each member of the commodity team was asked these questions through both a survey and a 1:1 interview (it was found that answers on the written survey were too brief, so most information was obtained from personal interviews).

This type of data collection may be regarded as subjective, but in this case significance is established in the fact that the results were very resounding. Those most affected by the changes – the pilot commodity team – praised the pilot for having freed hours of time and improved material balancing processes. Specific comments received from the commodity team included the following:

> "I think the pilot has gone great!"

> "We would always gap out before making a move, and often it would be the weekend or some other bad timing."

> "[Since the pilot started], there has been supply where it's supposed to be when it's supposed to be there."
>
> "Material balancing roles are much clearer."
>
> "Not as many diversions were happening [before the pilot]."
>
> "I now have 10-15 additional hours per week to devote to other responsibilities."

Every team member agreed that they wanted the new role to remain and the new processes to continue.

In addition to having achieved such broad consensus from multiple individuals in various organizations, we were able to tangibly show that we had reduced the steps in the material balancing process and that roles had been clarified (see Appendix C). Based on these achievements, we felt that we had met our objectives for organizational improvement. However, over the course of the pilot and more conversations with managers, we realized that there was another organizational benefit to be reaped: not just organizational improvement, but organizational *alignment.*

As explained in Section 3, prior to the pilot, ownership of material balancing was unclear. Again, 'official' responsibility lay with the BP, but that reality was highly difficult to achieve due to time zone and proximity problems. Consequently, the responsibility was a distributed one across the commodity teams. For some roles in a commodity team, significant ownership in material balancing tasks made sense. For example, PC had a critical stake in knowing when a factory may run short on a part and preventing that occurrence through transfers or diversions. Also, the SC3 team was an integral part of executing transfers and diversions, and so should play a critical role in material balancing. The RSM and Master Scheduler roles, by contrast, had been designed as strategic roles, and their frequent participation in material balancing tasks did not make sense.

This misalignment of responsibilities with roles was a direct result of a lack of centralized responsibility for material balancing tasks. After the pilot, it became clear that this misalignment had been eliminated. Responsibility for material balancing now lie specifically with the routing analyst, who was now US-based and could deal immediately with material balancing problems. The more strategic commodity team roles (the RSM, BP, and MS) now played support roles for material balancing rather than direct ones. The following diagram illustrates this realignment that occurred as a result of the pilot.

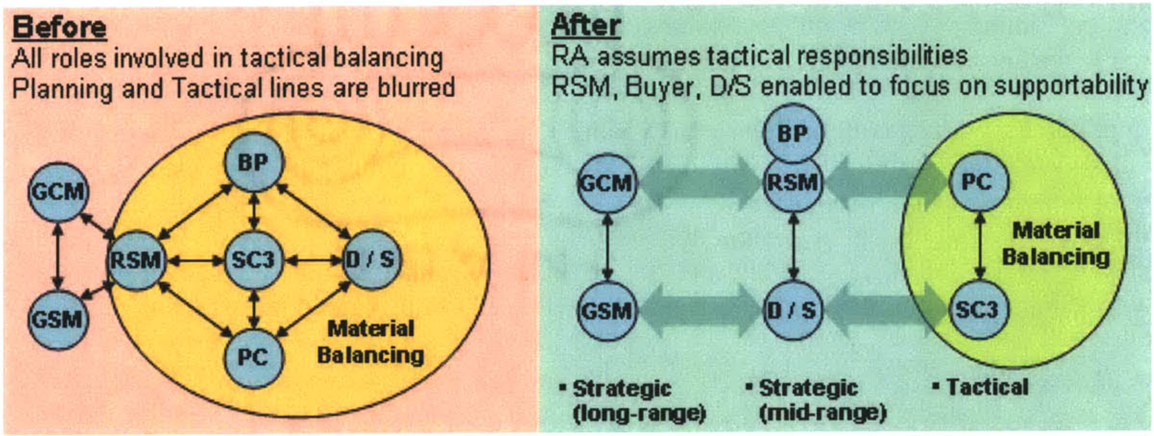


Figure 23. Strategic and tactical alignment of commodity team roles before and after the pilot.

This unanticipated benefit of organizational alignment became an important one for the success of the project. Group managers saw the potential to restructure the roles of their team members in positive ways, allowing more time for the tasks that they viewed as important to their team's success.

I was clear to us and our colleagues, having reviewed these pilot results in whole, that some or all of the policies undertaken should be continued. We created a recommendation based on the strengths of the pilot, and this recommendation was approved by Dell's manufacturing management.

5.5 Final Recommendations

There were two major components to our final recommendation: 1) Continue the routing analyst role, and 2) Expand the commodity scope gradually beyond the piloted commodity to include the next biggest expedite cost contributors.

Routing Analyst Responsibilities

Most of the routing analyst responsibilities were continued as performed during the pilot, but there was a realization that the role should be further leveraged. At the end of the pilot, BPs were still responsible for the reporting of part shortages on a daily basis. This led to delayed reports (due to time zone differences) and difficulties in clarifying the information. Dell's manufacturing management had begun a recent push to have very clear POCs (points of contact) for information. As a result, we decided to shift reporting responsibility to the routing analysts, who were physically seated next to the rooms and offices where manufacturing managers made their most critical decisions. This would add yet more weight to the new role as well as serve as 'free advertising' for the improvements we had made (based on experience during the pilot that these managers relied heavily on the routing analyst for assistance with resolving urgent material balancing issues).

Commodity Scope Expansion

Due to the high level of manual data-tracking required for material balancing decisions, it was clear that the routing analyst could not immediately take on all commodities. The transition needed to be progressive, so that commodity teams would have time to learn the new processes, and the routing analyst would have time to learn the details of each new commodity. Also, new routing analysts could be hired as needed during this progressive process.

In researching which commodities to take on next, an important realization was made: it was unlikely that the routing analyst would ever take on all of the commodities, as the ROI on the reduction of part shortages for most commodities was insignificant. The following diagram illustrates the fact that, after the top three contributing commodities (with exclusion of those categorized as "other"), the savings potential for each additional commodity becomes very small – not enough to warrant the routing analyst taking on all of the parts in those commodities.

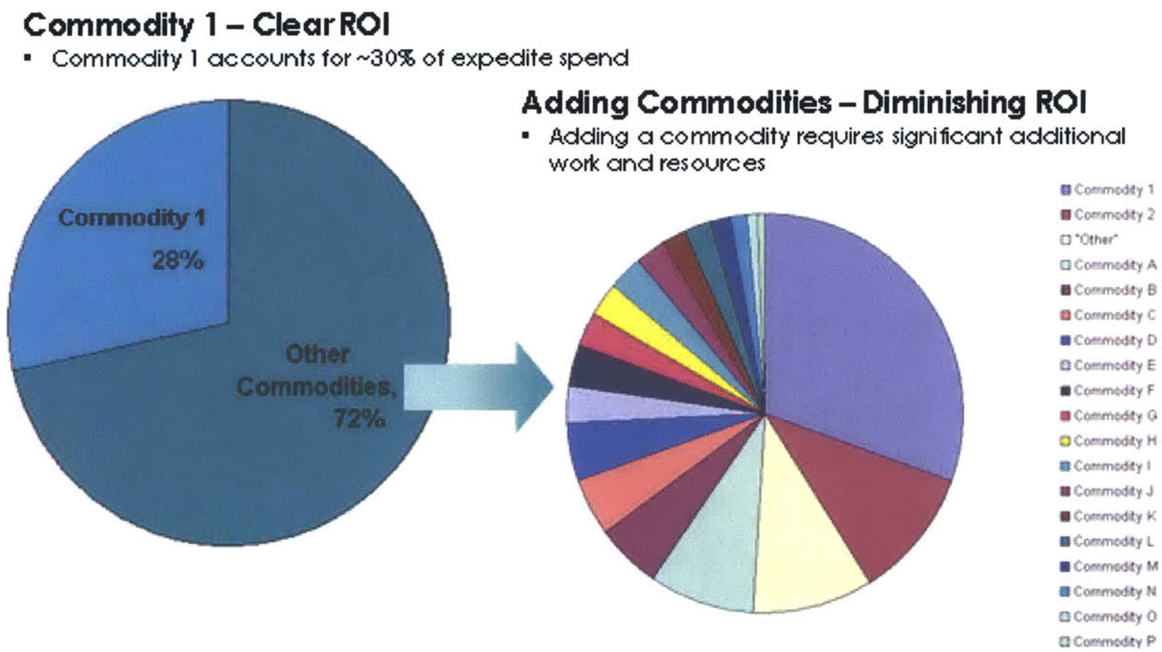


Figure 24. Contribution, by commodity, to Dell's costs for regional expedites attributed to material balancing problems in Q2 of 2005.

Upon this realization, we determined that a new commodity – to be referred to as "Commodity 2" – would be added to the routing analyst responsibilities next, and perhaps one or two other commodities in the future. The rest of the commodities would only be added as improved IT systems streamlined the material balancing processes to a degree that would automate a significant portion of the process.

These recommendations were well-received and approved by Dell's manufacturing management team. As of today – March of 2006 – work has begun with the Commodity 2 commodity team to add their parts to the Dynamic Replenishment Process.

6. Extension: Managing Rapid Supply Chain Growth

Throughout the course of this project, my awareness of "the bigger picture" grew as I came to understand the sources of the problems that I was addressing. I ultimately realized that the Dynamic Replenishment Project was a reaction to a single symptom of what was a much larger challenge: growth.

Section Two outlined Dell's well-known goal to reach revenues of $80 billion within a few years. This goal has roots in what has been Dell's overall strategy nearly since its inception: build-to-order, high volumes, and low prices (6). One Wall Street Journal author points out that "The plan has worked for 15 years... Now, some investors worry that the vaunted Dell effect is turning against the company as it requires ever larger market-share gains for steady revenue increases." (6) Another author, of the High-Tech Strategist newsletter, states that "Dell has grown too large to fight the tides in the market... its push into television sets and digital-music players is a contortion to maintain the growth rates they're promising Wall Street." (6) A number of analysts (and even managers who were interviewed at Dell) point out that it is worrisome that Dell has suffered slowing revenue growth in the face of a rebounding economy. Statements such as these and the statements (see Section Two) regarding logistical difficulties due to rapid expansion show evidence that Dell could be reaching a critical point in its growth. Dell's US, Global, and product expansion in the past five years were previously unprecedented, and Dell drives forward in this new environment with few analogous corporate guides to such explosive growth.

Note that this section is not a direct extension of the Dynamic Replenishment Project. Rather, it offers a supplemental view of the broader issues that drove the need for the project. I will share some insights, obtained throughout the course of my work at Dell, on a few specific areas that must be addressed by all companies in the course of rapid growth: development of IT systems, standardization, and organizational development.

6.1 IT Development

The topic of IT development is already well-studied and its issues well-understood. Therefore, I shall keep my insights succinct and focus primarily on more high level recommendations. In order to understand Dell's IT position as it existed upon my arrival, one must first consider Dell's culture. Specifically, consider the "just get it done" attitude that has, frankly, brought Dell much of its success over the years. One Dell manager, Ray Archer (at the time, VP of Americas Manufacturing Operations) was quoted in an article about "Dell's Supply Chain DNA" saying that "Our DNA is our culture of execution." I could not agree more based on my experience at Dell, and quickly realized that this culture had guided many aspects of Dell's IT development.

Dell did take many of the critical steps in constructing an essential IT foundation. Software vendors were brought in to install material management systems, supplier collaboration applications, and a number of related solutions. Throughout the course of this development, however, the development of mature collaborative systems was hindered by a few factors. First, Dell chose intentionally not to bring in an all-in-one solution, such as SAP, in order to accommodate their culture of rapid execution. An application like SAP would be far too cumbersome and would hinder the spirit of Dell's improvisational "get the job done" culture. As a result, most of the applications that were developed were independent of each other, presenting a number of future IT complications in 'connecting' the information from such applications and ensuring that their respective data were aligned. Second, many small applications were developed by various organizations to meet their specific needs. Sometimes these solutions were shared, and other times they were used by only one person or group. In many cases, major processes became highly dependent on these one-off applications, and support for them often became an issue once the original owner moved on from that particular position. Finally, in some cases, a focus on front-end application development had left gaps in the backend applications that support them.

Having witnessed the effects firsthand of making tactically focused IT decisions, I realized that there is a natural order to the foundational needs for IT systems. In order to leverage the general population's understanding of a similar well-known concept, I shall refer to this proposed set of priorities as the "IT Hierarchy of Needs", á la Maslow and his well established psychological "Hierarchy of Needs". Below is an illustration of the IT hierarchy.

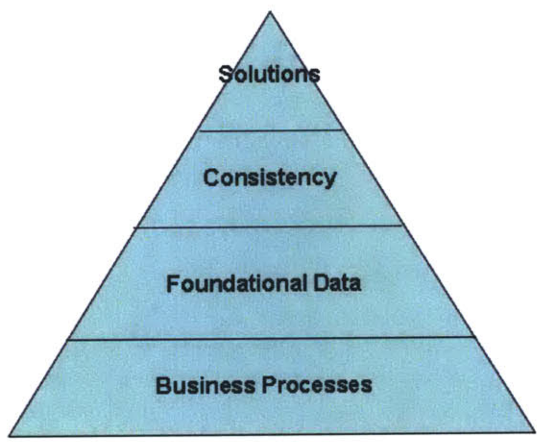


Figure 25. A proposed "IT Hierarchy of Needs".

This hierarchy reflects the idea that, in order to construct mature IT systems, the first consideration should be the business processes underlying those systems, then the basic information needed in order to support those processes, then consistency in the platforms and methods used to store and retrieve that foundational information, then finally the fully developed solutions that will make use of the data in order to support the processes. I have no doubt that many IT professionals would champ at the bit to explain why this hierarchy is oversimplified and does not address the true nature of IT development. However, my intention is to employ this as a way of thinking about the most fundamental elements of meeting informational needs as opposed to asserting a generalized IT development strategy. Many large organizations find themselves establishing IT solutions in reverse, from the top-down. Front-end solutions then struggle to link disparate data sources and to even find the data needed to support them, and often drive the redefinition of business processes to support the new application.

Many large organizations (especially those facing rapid growth) would benefit to give some consideration to this hierarchy. Specific actions might include documenting critical business processes, systematically rewarding foundational and strategic IT development (not just quick-ROI projects), and centralizing the development of front-end applications.

A Note on Supply Chain Visibility
Specific to supply chain IT systems, Dell faces one challenge that serves as a major hurdle to designing mature systems: vendor-managed inventory (VMI). Dell's inventory is not owned by Dell until it is pulled into one of its factories. Although this offers huge benefits to Dell's balance sheet, it presents a nightmare in the realm of supply chain visibility. Dell receives hundreds of thousands of parts every day from hundreds of suppliers. Each supplier owns the inventory en-route to Dell, and retains ownership over not just the inventory, but also any *information* about that inventory. Dell is generally able to obtain this information, but as a result of VMI, Dell must work through a large carrier in order to attempt to consolidate inbound supply information from all suppliers. This is not a simple task, and although Dell has made some major leaps in arriving at the goal of 100% inbound supply visibility, a number of challenges still remain.

To companies facing a similar challenge, few easy solutions exist. I offer two suggestions. First, ensure that information-sharing regarding inbound supply is an explicit part of initial contractual agreements with suppliers. Second, consider carefully the role of your carrier. Dell has utilized its carrier heavily in order to consolidate supply information, but is now dependent on that carrier for essential information, placing the carrier in a position of power. Use of a carrier for information consolidation may indeed be the best solution, as carriers have the resources necessary to collect and consolidate supply information. However, the decision should be made deliberately and steps should be taken to mitigate dependence on the carrier (e.g. develop proprietary software that consolidates the information and use the carrier only to obtain access to the data).

6.2 Standardization

As discussed in relation to the "IT Hierarchy", consistency is critical for the efficiency and capitalization of IT systems. However, IT is not the only aspect of a company's operations that may benefit from consistency, or *standardization*. Standardization may applied to many facets of an organization, such as processes, roles, and communications.

The argument for increased standardization at Dell is similar to the argument for consistent IT systems: Although Dell thrives on an improvisational culture, its large size and rapid growth may drive the need for increased levels of standardization in order to increase agility. It may be counterintuitive that increased standardization can improve flexibility. This would not be the case for a small organization. However, as an organization expands in numbers and geographically, the organization *as a whole* will gain agility from standardization, even though individuals lose some of their flexibility. Take the example of product prioritization policies in Dell's factories. If each factory is allowed to implement independent policies, the individual implementation of those policies is likely to be relatively fast. However, should the company – as a whole – decide to make a shift in the priorities of it products, each factory will react differently and at different times, causing a delay in the reaction to market changes. Although each factory is individually more agile, the company as a whole is slower due to limited standardization. In this manner, the benefits of standardization become greater as a company becomes larger and more complex.

This may be the story of Dell's position today. In the past, Dell's flexible processes and operations have served it well, but today's environment of rapid growth and increasing complexity offer potential benefits to even minor increments of standardization. The following graph reflects the idea that flexibility may improve with standardization for large companies such as Dell, although it will decrease if standardization levels become too high.

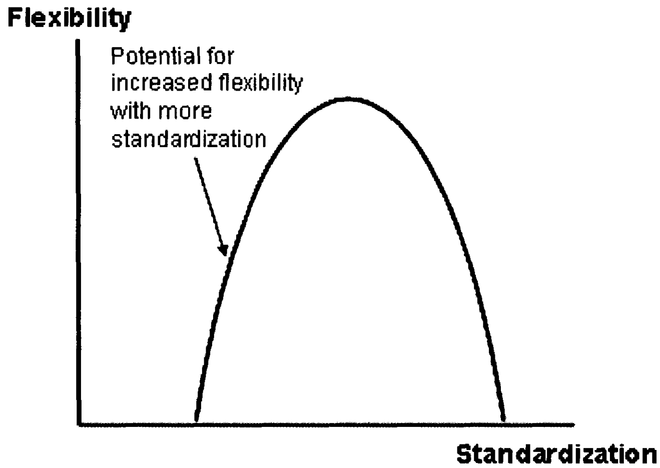


Figure 26. Some companies may experience an *increase* in flexibility with higher levels of standardization.

In recent years, Dell has indeed been taking steps toward higher levels of standardization – both in specific organizations as well as globally. Depending on Dell's precise location on the above flexibility curve, these efforts may help to drive increased flexibility in Dell's organization.

6.3 Organizational Structure and Incentives

Finally, it is inevitable that a company's organizational structure and incentives will need to evolve as it grows and becomes more complex. There are a number of ways to deal with organizational size and complexity, a few of which include:

- *Cross-functional teams*: As organizations become larger, cross-departmental communication becomes more difficult. Cross-functional teams help to maintain these critical links.

- *Managerial cross-training*: Encourage lateral movement in the ranks of management so that the solutions presented by various teams will be the best solutions for the company, not just for that manager's organization.

- *Proliferation incentives*: Especially in manufacturing companies which replicate operations at multiple sites, incentives should be offered not just for improvements to current processes, but also the *proliferation* of those processes to other sites. As knowledge is shared operations will both improve and become more standardized.

These are only a few examples of actions a company might take organizationally as it becomes larger. I offer a very short list because my intent is not to provide comprehensive instruction on organizational change for complexity, but simply to acknowledge organizational change as a critical element of the initiatives that a growing company must consider.

My experience during the Dynamic Replenishment Project was that Dell has indeed taken on a number of these change initiatives and is likely to progress with them in the future. The organizational environment is a dynamic one, where roles and organizational structures are continuously evaluated, and management is open to change. Cross-training is encouraged at Dell at all levels, and I also noted that IT organizations had begun implementing incentives for the global proliferation of new applications. These were all positive signs that Dell understands the need for organizational change, and is striving to create the organization it needs to succeed in the future.

7. Conclusion

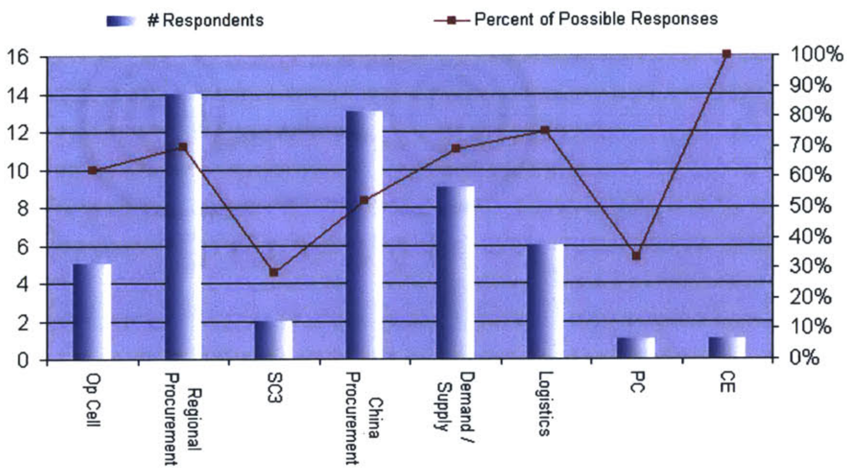
Dell's growth since its inception in 1984 has been nothing short of spectacular. The company must be commended for its constant innovations in operations including VMI, demand-shaping, cash-cycle leverage, and the mastery of build-to-order manufacturing. In recent years, however, Dell's relentless pursuit of increasing market share has brought about geographic and product expansion well beyond what was experienced before the start of the new century. This expansion has carried Dell into a new and complicated supply chain environment also faced by many of its competitors. Among a multitude of challenges introduced by this expansion is the challenge of material balancing.

Global supply chains with longer lead times and expansions of manufacturing locations as well as product portfolios have made it increasingly difficult to accurately forecast the final destination of supply. This, in combination with industry-wide constraints of supply for certain commodities, has led to increased part shortages at Dell as a result of material imbalances. The problem of material balancing has become so expensive for Dell that a renewed focus on supply routing is necessary. This focus should be obtained by retaining the newly instituted role in the supply chain organization (the routing analyst) whose responsibility it is to ensure that supply is routed to the correct location as it arrives at its US port from Asia. The continuation of this role should lead to reduced part shortages, lower logistical costs, clearer process, and improved organizational health and alignment.

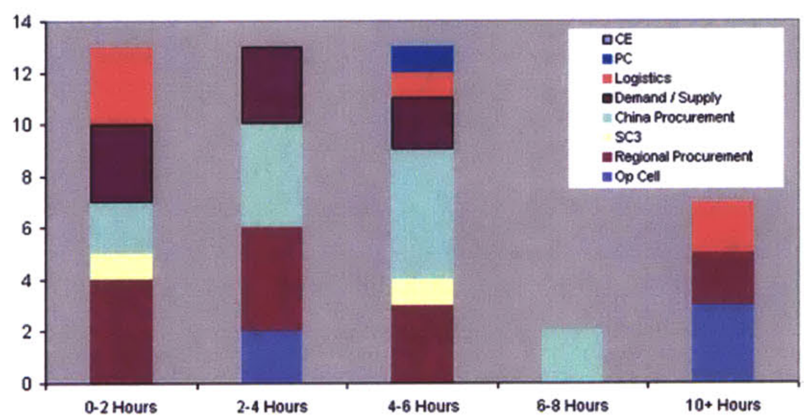
The problem of material balancing is one of many that will be faced as a result of rapid growth at Dell. Dell's seemingly unbounded growth rate has inflated market expectations and left the company in the difficult position of continuing to meet those expectations in an ever more complex environment. In order to continue meeting these expectations in the face of such complexity, Dell must address related challenges, such as the development of improved IT systems, higher levels of standardization, and the need for organizational evolution.

The future for Dell is likely to bring more of the same: increases in US and global locations, increases in SKUs, and ever-more demanding customers. Ultimately, this means higher complexity in the face of higher customer expectations. This future underscores the need for continued focus on improving supply chain operations through process clarity, organizational clarity, and improved IT infrastructure. Implementation of the Dynamic Replenishment Project was a large and commendable step in this direction. Should Dell take the continued steps necessary to succeed in an ever-more complicated supply chain environment, they will continue to capitalize on the strengths they have so passionately and successfully developed.

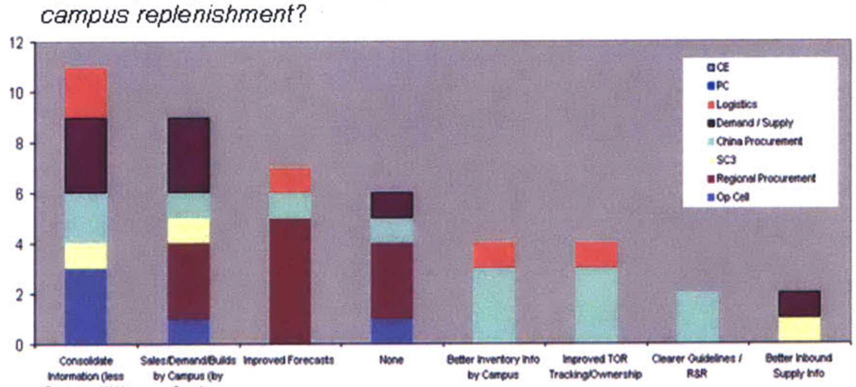
Appendix A Material Balancing Survey Responses



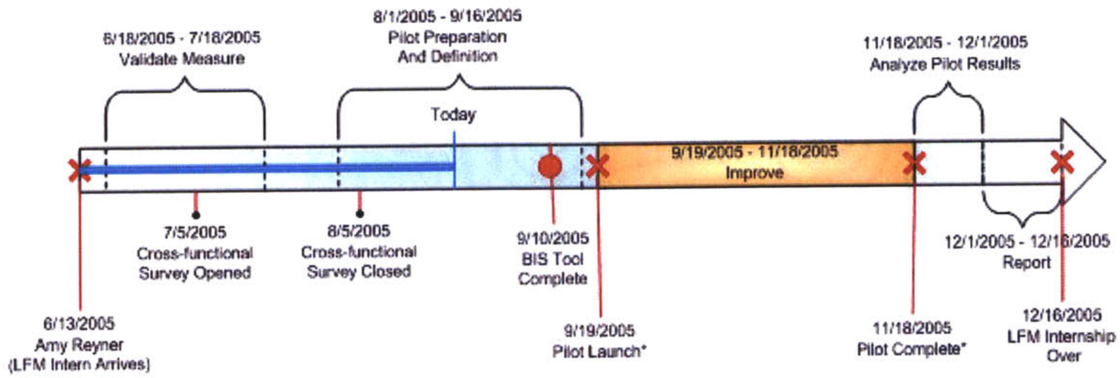
How much time, per week, would you estimate you spend on issues that are directly related to the complexities of multi-campus replenishment? (e.g. handling a material expedite due to campus imbalance).



What improvements could be made to your tools and resources (e.g. Reports, Systems, etc.) that would help you execute your duties related to multi-campus replenishment?



Appendix B Dynamic Replenishment Project Timeline



FY07 Action Plan

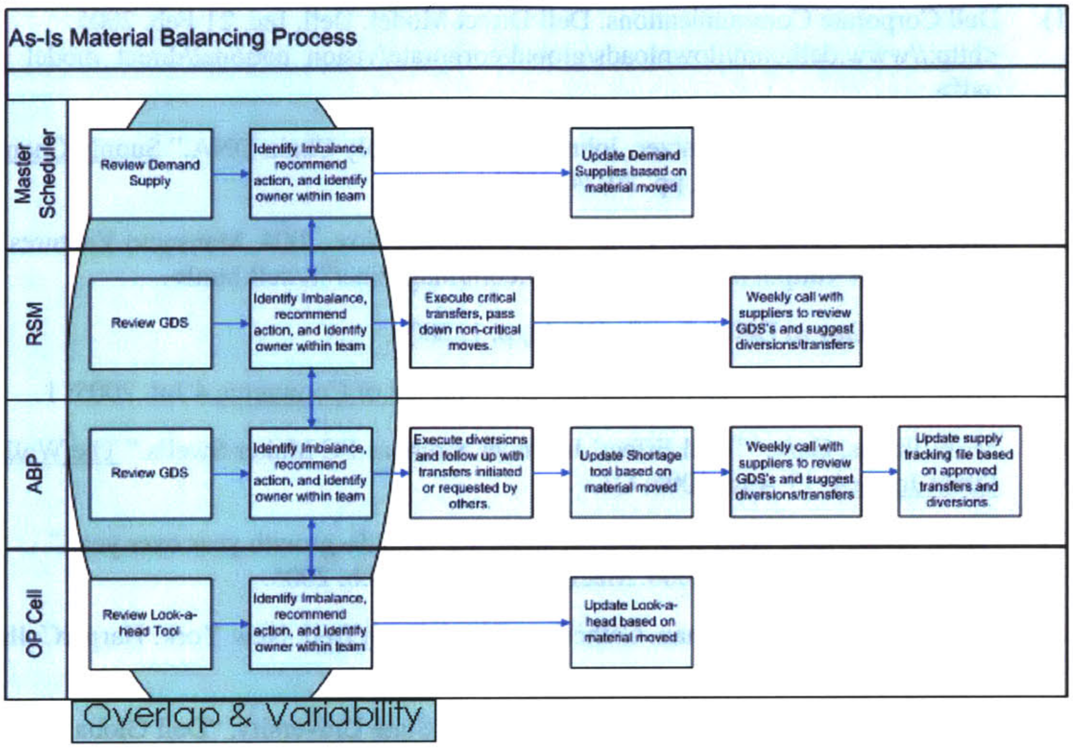
Q1:
-Circulate pilot findings, obtain organizational buy-in.
-Roll-out to eligible commodities, based on resources.
-Report final project impact.

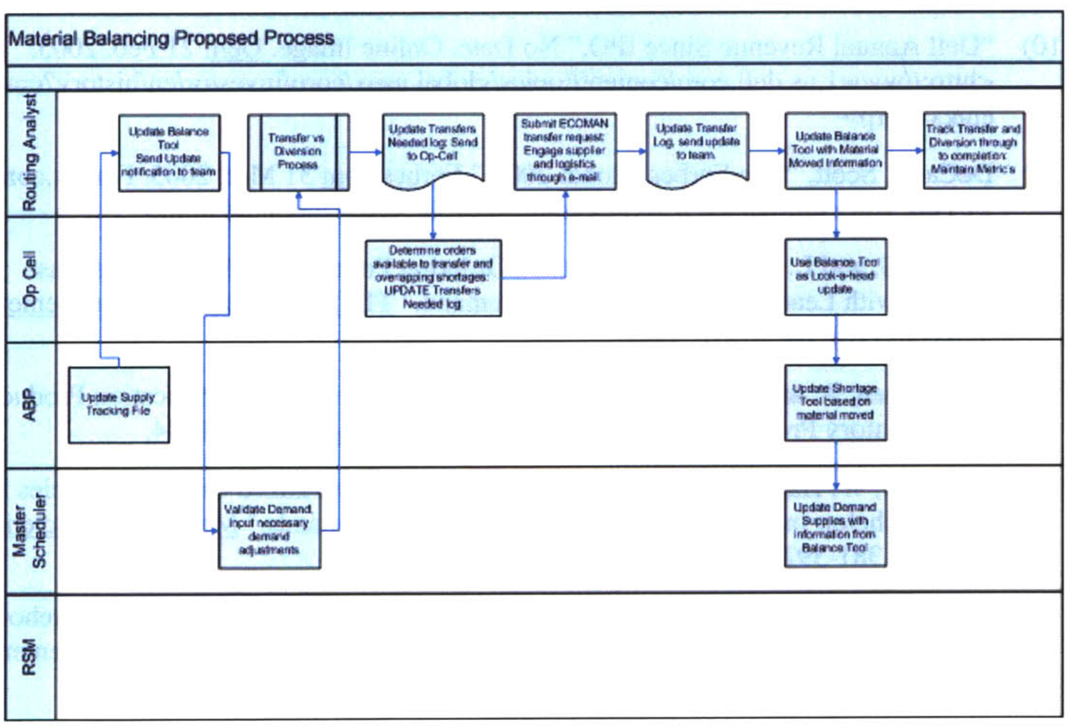
Q2-Q4:
-Highlight I.T. recommendations learned from the project.
-Leverage I.T. developments toward the success of the project.
- Dynamic Routing
- ECOMAN 2
- Shortage Tool/Part Recovery Enhancements

-Roll out further commodities as I.T. enhancements allow.

NOTES:
- Dates are approximate based on data compilation.
- Current Commodities highlighted for phased roll-out are Chassis, CRT's Keyboards, and speakers.
- Full implementation contingent upon Dynamic Routing success, and LIFT Enhancements.
- Obtaining sales by location being pursued.

Appendix C Initial balancing process vs. new process





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