REDUCING THE COST OF QUALITY (COQ) THROUGH INCREASED PRODUCT RELIABILITY AND REDUCED PROCESS VARIABILITY

by

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Submitted to the Sloan School of Management and the
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Master of Business Administration
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ABSTRACT

Today, Dell, Inc. (Dell) spends millions of dollars each year to prevent product defects from reaching the end customer and to manage those product defects that have escaped to the end customer. The cost of the equipment, labor, and materials to prevent and manage product defects is referred to as Dell's Cost Of Quality (COQ). A large percentage of Dell's COQ is spent by warranty-support and customer service organizations (Services). While the costs of defects most directly affects Dell through the expenditures in such Service organizations, the causes of defects are found predominantly in other organizations, such as Design, Materials, and Manufacturing. Without a causal link which directly ties the costs of quality defects to the causes of quality defects, it is difficult to justify increased quality-improvement expenditures in product design, product validation, component selection, or manufacturing processes. The Cost Of Quality methodology described here is a practical approach to a) quantifying the financial impact of quality defects, b) shifting the problem-solving focus from "find-and-fix" to prevention, and c) prioritizing quality improvement investments based on expected financial return. This methodology aligns well with Dell's focus on financial performance and has provided the foundation for a COQ program which has been adopted by Dell's Executive Office as one of five top cost reduction projects for fiscal years 2005-2007.

This paper provides background on the current tools, process, and culture affecting quality at Dell, describes the financial impact of quality on Dell's business, details the evolution of Dell's COQ initiative, and analyzes five possible methods to sustain the COQ effort.

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INTRODUCTION

Dell is targeting a multi-billion-dollar reduction in Operating Expenses by fiscal year 2006 (FY'06). This target, established by Dell's Executive Office, is intended to be in addition to any cost reduction projects already defined and is intentionally larger than that which can be achieved through traditional cost reduction methods. It is the intention of the Executive Office to use this goal for a reduction in Operating Expenses (OpEx) to stimulate new, creative, "out of the box" solutions.

This thesis describes one cost reduction opportunity that Dell has not previously focused on in a concerted way: the Cost Of Quality (COQ)...or, more accurately, the cost of un-quality. The COQ includes the cost of managing failures in the lab, in the factory, and in the field (the cost of non-conformance), as well as the cost of testing and inspecting functional products/parts (the cost of conformance). Dell routinely works to improve the quality of specific products and specific platforms (see Appendix 2 for an illustration of the relationship between platform and product). Today, however, this quality improvement work is often after a failure event has occurred. And the solutions implemented are often product-, not process-based.

The COQ initiative at Dell is a problem-solving approach that targets quality improvement as a mechanism to reduce costs, focuses on process-based solutions, and requires cross-organizational problem solving teams to be successful.

Chapter 1 discusses the strategic, organizational and cultural environment at Dell to provide an understanding of the atmosphere in which quality decisions are made.

Chapter 2 defines Cost Of Quality (COQ) in general and discusses the process used to measure the COQ opportunity at Dell.

Chapter 3 describes the process of persuading a broad constituency of Dell executives that COQ is different than quality improvement efforts previously pursued by Dell.

Chapter 4 describes how executive-level commitment for an ambiguous goal was translated into an action plan for Dell to execute.

Chapter 5 discusses the sustainability of the COQ initiative at Dell.

CHAPTER 1 – THE DELL ENVIRONMENT

To better understand how decisions regarding quality are made at Dell, it is instructive to briefly evaluate the strategic, organizational, and cultural environment in which these decisions are made. The strategic environment is the corporate direction defined by the Executive Office and the competitive advantage that Dell is attempting to develop and maintain. The organizational environment is the formal and informal reporting structure upon which the company conducts its daily business. The cultural environment is largely an emergent one, derived from the norms, practices and behaviors of the majority of employees over time. Clearly, for the company to move forward in a unified manner, it is necessary for the strategic, organizational, and cultural environments to be internally consistent and to be sufficiently aligned. Projects and proposals which have the potential to upset the existing strategic, organizational or cultural environment may face fierce resistance within the company.

Dell's Strategic Environment

Dell's strategies are often summarized by the Dell Direct Model. The Direct Model has been documented often and I therefore leave it to the reader to investigate further if a more thorough understanding is desired. For the purposes of the project, it is sufficient to simply summarize the Dell Direct Model with the five key tenets:

1. Sell direct to customers
2. Utilize industry standard components
3. Build to order
4. Manufacturing batch size = 1 unit
5. Positive Conversion Cash Cycle (CCC)

The Direct Model is primarily a recipe for Dell's operational strategies. This Model describes the tools that were used to transform Dell in 19 years from a single employee making computers in a college dormitory room to a multi-billion-dollar personal computing empire. While these tools are certainly a piece of the Dell Strategic Environment, they fail to describe the direction of Dell's business. Dell's business strategies described below, combined with the Direct Model, guide the company's direction for marketing, product development, and resource-allocation.

First and foremost, Dell's business strategies mandate a low-cost operation and a low-price product position. With Operating Expenses (OpEx) less than 10% of revenue (see Appendix 1), Dell maintains the lowest OpEx in the personal computing industry, less than half of that of Hewlett-Packard or IBM. This focus on OpEx is consistent with the Direct Model's stated utilization of industry standard components, leading to minimal R&D and product design expenditures. However, this focus on OpEx results in more than just an industry-low R&D expenditure rate. Dell's focus on OpEx drives every organization to reduce its employee-base to the lowest possible levels. For a quickly-growing company such as Dell, this typically translates into hiring employees at a slower rate than the revenue growth rate. For companies that are growing less quickly than Dell, a strategy that focuses on reducing operating expenses may instead necessitate Reductions In workForce (RIF's). Obviously, employees are more receptive to an OpEx reduction strategy when it entails slow hiring than when it entails layoffs. This

becomes an important factor in Dell's Cultural Environment, supporting and reinforcing the OpEx reduction strategy.

This focus on OpEx reduction is visible at every level of the company. Organizations at Dell, whether in the factory, technical support, or product design, proudly describe themselves as "lean and mean". Combined with Dell's build-to-order manufacturing approach, a goal to reduce OpEx goal creates additional pressure on Dell's limited manufacturing and fulfillment resources to ensure that customers promptly receive the product that was ordered. This has the potential to impact product quality in the field.

Consider a hypothetical failure that is discovered at final test in the factory, resulting in a software loading problem. Suppose that the Electrical/Mechanical Repair (EMR) team determines that replacing the motherboard appears to correct the failure, allowing for software loading to proceed uninterrupted and for the product to ship to the customer on time. The EMR team sends the removed motherboard to the original supplier for failure analysis and, if this problem were to repeat, the EMR technician calls the factory Product Engineering group to investigate the failure further. The factory Product Engineering group, being a reduced OpEx team, has no idle engineers to immediately work on this failure and the team is already working on a backlog of other issues. For the Product Engineering team, priority is always given to those issues that impact shipping products to a customer. As this issue does not immediately impact customer shipments, it is of lower priority. Suppose that the root cause for this failure is not the motherboard but instead an intermittent failure of a connector on the back of the system. If this were the case, replacing the motherboard did not solve the problem; subsequent attempts to load the software may have been successful even without a new motherboard. The removed motherboard would be identified as "No Trouble Found" or "Can Not Duplicate" (CND) at the supplier failure analysis lab and would be returned to Dell. Contrast this to manufacturing operations which utilizes the Andon cord. In such a factory, all assembly for this product would have been halted until root cause for this failure was determined. However, in a build-to-order factory with limited engineering resources, this approach is not possible without significantly impacting customer deliveries. This is an example of the trade-off between build-to-order speed and product quality which Dell must continually evaluate.

Dell's financial focus is an integral part of its continuous improvement process. Prior to initiating a Business Process Improvement (BPI) project (see Appendix 3), all proposals require an Executive-approved business case analysis with a 12-month expected return on investment. Throughout the company, metrics are routinely translated into their financial impact on the company; employees acknowledge that decisions are made primarily based upon financial considerations.

Dell has an aggressive growth strategy, targeting a doubling in revenue (from $31B to $62B) over a period of 5 years. More than two years after establishing this target, Dell is on pace to successfully double its revenue on schedule. Dell's growth is almost exclusively natural growth, without acquisitions, reflecting the belief that the Dell culture is sufficiently different from other companies' cultures, such that a growth-by-acquisition strategy would be unsuccessful. With year-over-year growth in personal computers (PC's) less than necessary to double Dell's revenue, Dell has adopted a strategy of growth that includes entering new markets, such as high-end servers, storage products, digital projectors, MP3 players, Personal Digital Assistants (PDA's), and flat panel televisions.

Interestingly, the pressure to meet these growth goals has led Dell to adopt strategies that are, in some cases, digressing from the Direct Model. For example, the decision to quickly enter

consumer electronics markets such as MP3 players and flat panel televisions has led Dell to abandon the Direct Model attributes of build-to-order and single-unit manufacturing batch size.

Consistent with a strategy of reducing OpEx, Dell strives to be the low-price computing provider, offering acceptable performance and quality at the lowest possible price to the consumer. As Dell enters new markets, Dell has a fixed profit margin target that is often significantly lower than existing market competitors. Rather than entering the market at a price point that is marginally below the existing suppliers, Dell has routinely chosen to enter the market at a price point that is consistent with its fixed profit margin target. This often allows Dell to dramatically undercut existing prices, to significantly disrupt the market, and to aggressively capture market share.

Dell's Organizational Environment

A company's organizational environment describes both the formal and the informal organization structure that dictates how the company operates on a day-to-day basis. At Dell, both formal and informal organization structures play a critical role in the company's operations. The most critical aspects of Dell's organizational environment are the rapidly changing organizations, the strong role of informal networks, and the metrics-driven behavior of organizations.

In response to changing market conditions and a changing competitive landscape, Dell's formal organizations are perpetually in transition, with major re-organizations announced approximately twice each year. In fact, employees have not only become accustomed to organizational changes, but have come to expect them, even to the extent that some employees will express anxiety if it has been some time since the previous change. Working within such a highly dynamic environment encourages employees to develop a broad skillset, which can be transferable to a new organization, and naturally leads employees to develop wide informal networks across the company. Employees routinely engage their informal network for data, guidance, or assistance in getting their job done. In some cases, this informal network is the unspoken glue that binds the organization together.

Dell's formal organization structure is fundamentally broken into three categories: hourly-paid employees in the factory and service organizations, salaried employees, and Executives (Director-level and above). For many salaried employees, a primary career goal is reach the Executive ranks. Periodically, Dell will make a corporate-wide communication, announcing new Executive appointments. These appointments are the result of a lengthy evaluation process including panel interviews with existing Executives. While not a formal requirement to be promoted to Director, it is understood that it is very advantageous to have an Executive mentor who sponsors the promotion. This, coupled with the panel interview process, ensures that promotions to the Executive ranks receive broad support from a number of existing Executives. The need to have broad Executive support encourages aspiring employees to become visible to Executives across many organizations. Such a promotion process reinforces the importance of a broad informal network at Dell, but can also lead to deference to Executives' opinions. While most employees are generally aware of the importance of such an informal network, some employees are more direct in their need to establish and maintain strong ties throughout Dell's Executive ranks.

While the dynamic nature of organizations and the informal network both play an important role in Dell's day-to-day operations, perhaps the most powerful organizational force at Dell is the company's pervasive metrics. Metrics abound at Dell and the power of these metrics is omnipresent. At every level of the company, Dell employees are aware of their organization's

metrics, aware of how their job affects those metrics, and are expected to adjust their behavior to maximize their performance as measured by those metrics. Indicative of the importance of organizational metrics, the VP of Operations is paged every two hours with the factory's performance numbers from the previous 120 minutes. Wherever possible, organizational metrics are translated into their financial impact on the company. This is consistent with Dell's strategic focus on reduced OpEx and allows metrics to be compared, using financial impact as a common language. However, some metrics can be more difficult to directly translate into financial impact. Examples of such metrics include: safety, quality, employee moral, intellectual property, and customer loyalty.

The power of metrics-based behaviors has been a driving force for Dell's financial success (see Appendix 1). However, challenges exist in any organization that is highly metrics-oriented. One such challenge is the tendency for local optima leading to corporate sub-optimizations. It is conceivable that an employee may successfully improve personal or organizational metrics by a marginal amount and that such an improvement may result in significant negative impact to metrics for other portions of the company. Another challenge is for easily-measured actions to take priority over difficult-to-measure actions. For example, if improvements in factory productivity are known to have a direct relationship on corporate profitability, productivity improvements may be pursued ahead of improvements in factory safety or product quality, which may have a less direct relationship on profitability. Similarly, it may be more difficult to measure an organization's performance in preventing defects than it is to measure an organization's proficiency in efficiently managing defects. As a result, some metrics-oriented organizations may tend to focus on easily-measured defect metrics, such as field failure rates, over prevention metrics, such as the efficacy of FMEA's to identify and prevent potential defects, which are more difficult to accurately measure.

Dell's Cultural Environment

The cultural environment of a company describes the norms and expectations, spoken and unspoken, that shape employees' expectations of one another. While it is possible for the management of a company to simply dictate the cultural environment, often the cultural environment is a blend of top-down cultural directives and bottoms-up cultural beliefs.

Dell is a non-union working environment which encourages direct communication between employees. Expressing Dell's egalitarianism and the pragmatic need for flexibility, every employee has a cubicle office with six-foot temporary walls. No office has a door, reflecting the company's "open door" communications policy. It is widely known that the VP of Operations will never refuse a request for a one-on-one meeting with any employee. In general, most employees will put their current work aside to help a fellow employee when asked. Employees change jobs very frequently, as a result of project completions, re-organizations, or career advancements. Most Dell employees are not just embracing of change; they have come to demand it.

Dell actively seeks to hire competitive personalities and promotes friendly competitions between organizations in the pursuit of continuous improvement. Overall, Dell is a friendly and open work environment, where employees are often at ease talking about issues in their personal lives. Jokes and friendly banter are heard throughout the day in the aisles and in the meetings. By and large, employees are not treated simply as employees, but as *people*. Dell managers are generally accommodating when employees' life issues require time away from the office. But just as employees' personal lives play an active role in the Dell workplace, the workplace plays an active role in Dell employees' personal lives. Many employees carry pagers, two-way

handsets, or cell phones. Unlike other companies, where paging an employee is a last-attempt effort used only for an emergency, Dell employees will often page one another for routine communications. Often, employees are expected to be electronically accessible, via pager, e-mail, or cell phone, at any time of the day or night.

Dell can be a demanding work environment. Dell managers, from the CEO on down, openly express the belief that there are "no excuses" for failing to meet commitments. With short product life cycles, time-critical customer expectations, and increasingly limited resources, employees often work long hours to get their jobs done. Some employees brag about their excessive hours at work. However, Dell managers are far less likely to focus so pointedly on an employees' time at the office, focusing instead on an employee's ability to get the job done. With continued pressure to further reduce Dell's OpEx, limited resources become even more limited and some employees indicate that they feel as though they are running from fire to fire.

Dell is an exceedingly customer-oriented company. This is a result of Dell's direct engagement with the customer, from the customer's order placed directly with Dell, to the product built expressly for that customer, to the customer service managed by Dell employees in one-on-one conversations with the customer. To illustrate Dell's commitment to the customer, consider this true example:

On October 8th, an all-day meeting was held in Austin with four VP's and six Directors from Design, Procurement, Manufacturing, and Services to discuss Dell's COQ project. Near the end of the meeting, the speaker phone in the conference room rang. It was answered and the person calling indicated that he was transferred to this number and wanted to change his order for a product. It was clear that this was a Dell customer that was erroneously transferred to this conference room. The Executives in the room dropped what they were doing, nearly tripping over each other in an effort to find the customer an appropriate escalation phone number to resolve his issue. The customer indicated that he wouldn't mind simply calling back to the original 1-800 number, but these Executives didn't want to let him off the phone without helping him get what he needed. It was clear by their words and their actions that these Executives really believed that serving the needs of the customer is their primary responsibility as Dell employees.

CHAPTER 2 – DEFINING COST OF QUALITY

A quality culture vs. a low-cost culture

Seven years ago, I was leading a supplier selection process for a custom, 750W power supply to be used in a high-end multi-processor server. After thoroughly measuring and evaluating more than twenty suppliers, the selection came down to two companies: Company A and Company B. Company A was a large, sophisticated company with many product lines, a fully-automated lights-out warehousing system, world-class failure analysis facilities, capability to perform high-precision wire-bonding, and a demonstrated record of low failure rates. The engineers at Company A had previously designed and manufactured many high-end power supplies and indicated that they could modify a previously designed 1200W power supply to meet my specification for a 750W power supply. Company B was also a large company with many product lines. Company B's warehousing system was entirely manual and failure analysis occurred at the engineers' desks, right alongside work on new product designs. All of Company B's solder joints were formed either with an older wave solder process or manually. Company B had a demonstrated record of improving failure rates, but had not attained the failure rate level that Company A had attained. Company B had never previously manufactured a high-end power supply, but indicated that its highest wattage power supply, at 400W, could be modified to meet my specification for a 750W power supply. When I met with both companies to review their design proposals, each presented their estimated price. Company A's price was almost exactly double that of Company B.

Which of these two companies had a "quality culture"? To answer this question, we must explore the meaning of quality.

To many, "quality" conveys the image of a dizzying array of alphabet soup: TQM, SPC, DOE, 6σ, MIL-STD, FMEA, AOQL, QFD, MTBF, OOC, with a QA or QC organization more interested in statistics which show what cannot be done than in designing and manufacturing products for the customer (see Appendix 7). Certainly, a quality culture is not one in which such quality tools are used indiscriminately or without understanding how those tools will better meet the needs of the customer.

Understanding that quality is measured by the customer (Pyzdek, 1), it becomes clear that a quality culture is one which excels at understanding and satisfying the needs of the customer. Quality is more than simply failure rate. Quality is any discernible difference, *as valued by the customer.* If the consumer can discern a difference in the product and is willing to pay for that difference, the product has a superior quality attribute. With this in mind, it becomes clear that in the above example, Company B had the quality culture, while Company A had invested in an expensive infrastructure that did not help to satisfy the customers' needs. A quality culture is one in which the customers' needs are well-understood and precisely met. This would imply that a company with a quality culture should not deliver a high-performing attribute which the customer is unwilling to pay for.

All customers for all products have some expectation for product performance, price, delivery, and failure rate. As the "quality culture" is one which attempts to perfectly understand and meet the customers' needs, a quality culture should also be a low-cost culture which seeks to satisfy the needs of price-sensitive customers. The reverse, however, is not necessarily true. A low-cost culture may unwittingly reduce the cost of the product or process in a manner that reduces the product's ability to meet the needs of the customer.

To quote a company poster, Dell's Direct Model "begins with the customer and ends with the customer". Dealing directly with the customer during the ordering process, Dell has the ability to determine the price elasticity of product features and to perform conjoint analyses in a real-time manner with actual customers. With this and other usability data directly from the customer, Dell understands its customers' needs extremely well. It is through this understanding that Dell makes decisions about which features to include in a product at which price. It is Dell's strong customer-oriented quality culture that has enabled Dell to understand and meet the customers' needs, while not exceeding the customers' needs with unnecessary costs.

Refusing to exceed customers' needs seems antithetical to a quality initiative and can be as difficult as meeting customer expectations. However, consider technology innovations such as Bluetooth. Some manufacturers of laptop computers incorporate a Bluetooth transmitter and receiver into the product to allow customers to transmit data wirelessly over short ranges. Dell's choice to not include Bluetooth features in its laptop designs reflects Dell's belief that customers do not value such a feature. Similarly, it would be possible to design a desktop computer with a twenty year expected lifetime. Dell understands the customers' needs for product reliability and has made design choices which result in a lower-priced desktop computer with an expected lifetime significantly less than twenty years. When customer data indicates that product improvements are not sufficiently valued by the customer, it takes both courage and accurate customer data to know when the appropriate quality decision is to decline a technology advancement (such as Bluetooth accessibility) or an improvement in product reliability.

Dell designs products with a continuous improvement approach to quality, seeking failure rates at the lowest possible price, consistent with the notion that "If it's good enough for the customer, it's good enough for us". To this end, Dell uses data in a manner that is slightly different from other companies. Dell is a decidedly data-driven company, but often seeks to use data to determine which decision is "directionally correct," rather than to arrive at a precisely-determined decision. When Dell managers elect to use data to make a directionally correct decision, they are reflecting the notion that a first-order analysis quickly arrives at a decision that may not be precise, but is close enough to guide the decision. Where other companies may become stuck in the quagmire of "analysis paralysis", Dell's directionally-correct decision-making process is very quick and not excessively resource-intensive. This aligns well with Dell's desire to be highly agile and to minimize OpEx. With this decision-making approach, even an incorrect decision can be quickly readdressed. At Dell, it is widely believed that a partial solution implemented quickly is better than a perfect solution delayed indefinitely. Such a directionally correct decision was instrumental in the COQ effort to move the project forward when the data proved to be insufficient (see Chapter 4).

Dell's (and Dell's competitors') ability to understand and meet the needs of customers can be measured through customer surveys, such as those conducted by Consumer Reports. A survey of more than 54,000 respondents published in the December, 2003 issue of Consumer Reports indicates that Dell's failure rate is second best in the personal computer industry behind Apple (see Appendix 4). Even with a survey accuracy of ±2.5% and a relatively tight distribution of failure rate data among personal computer competitors, Dell is among the top three suppliers (with Apple and IBM), but with significantly lower prices than either Apple or IBM (see Appendix 5).

With respect to Technical support, another Consumer Reports survey of 4,100 respondents indicates that Dell is again second best in the personal computer industry behind Apple (see Appendix 4). With an overall score of 62, customers are, on average, "fairly well satisfied" with

Dell's Technical support. With a survey accuracy of ±2% and a much broader distribution of data, Dell is clearly among the top three suppliers with respect to Technical support.

In terms of features and performance, Consumer Reports rates Dell "Very Good" or "Excellent" for mid-range desktop computers, high-end desktop computers, desktop replacement laptops, and lightweight laptops ("Desktop Computers:" 52 and "Laptops:" 19). These, of course, are only a small measure of overall customer satisfaction and are an imperfect measure of Dell's ability to understand and meet the needs of its customers. However, this data tends to indicate that Dell is successfully meeting customer expectations and providing a product offering that is competitive with other personal computer manufacturers. Another measure of Dell's ability to meet the needs of its customers is its dramatic increase in revenue over the past 17 years (see Appendix 1). Dell's rapid growth of sales is a demonstrable assertion of Dell's ability to meet its customers' needs.

When benchmarking other companies which are renowned for their robust (and resource-intensive) quality improvement systems, it is reasonable to also compare financial success of the two companies as well. Where Dell's financial success surpasses that of the benchmark company, one is likely to question the value in emulating the benchmark company's quality system.

Evaluating Dell's price performance relative to its competitors, it appears that Dell is quite competitive with its laptop products, although other companies have become the price leaders for desktop computers. Appendix 5 shows prices for selected desktop and laptop computers from seven personal computer manufacturers, as determined by data from their websites. While Dell is the second least expensive supplier for comparable laptops for the home office customer (4.8% above Compaq's price), Dell is in the middle of the pack for entry-level desktops, some 27% more expensive than Compaq. The conclusions in Consumer Reports are similar. Dell offers the lowest priced laptops in their evaluation of both desktop replacement laptops and lightweight laptops ("Laptops:" 19) and is in the middle of the pack for both mid-range desktop and high-end desktop pricing ("Desktop Computers:" 52).

So, if Dell is successful, as measured by customer surveys and sales growth, in understanding and meeting the needs of its customers, wouldn't a COQ project push Dell to reduce failure rates beyond the customers' expectations and unnecessarily add cost to the product? Using the earlier asserted definition of quality as the ability to precisely meeting the customers' needs, it could be argued that improving failure rates beyond customers' needs is actually an action that will reduce the company's ability to deliver a product that is valued by the customer. If not carefully designed, it is very possible for the COQ effort to be a resource-consuming project yielding a questionable improvement in the value of Dell's products, as perceived by the customer. With some indication that Dell is already delivering an acceptable defect rate to customers, a project such as COQ which attempts to further reduce defect rates must be justified financially.

Defining Cost Of Quality

As reflected in Dell's Business Process Improvement "DMAICR" methodology (see Appendix 3), the most important step in problem-solving is often a concise definition of the problem. The objective of COQ was defined as:

> "Achieve a major cost reduction through reliability improvement and variation reduction in Product Designs, Manufacturing Processes, Supplier Management Processes, and Services."

The Cost Of Quality initiative is an attempt to focus on process-based root causes for a problem and to implement corrective actions in a way that will prevent process-based problems from re-occurring in the future. The key to COQ is the project's motivation – to achieve a major cost reduction. Note that the primary of objective of COQ is not to improve failure rates, not to install new or improved corporate-wide quality systems, and not to implement product improvements that the customer does not sufficiently value. The COQ project is first and foremost a cost-reduction activity. As demonstrated by surveys of customers with respect to field failure rates, Dell is satisfactorily meeting customers' needs. Any further improvements in failure rates are therefore compelled to demonstrate a positive Return On Investment (ROI). With increased attention on reducing OpEx, the timing is right for a dramatic cost reduction proposal such as COQ.

Chapter 3 will discuss more thoroughly how COQ is different than Dell's other failure-reduction initiatives.

To clarify the concept of COQ for Dell employees, the following was developed to define the scope of COQ and to clearly define was is part of COQ and what is not:

Scope : Dell hardware, software, and services
Internal and external customers that receive data/output

COQ is the cost of...	CAUSES: Design	Mat'ls	Mfg	Service
• rework, repair	X	X	X	
• failure analysis, scrap, teardown	X	X	X	
• inspection, audit		X	X	
• supplier yield loss		X		
• warranty costs	X	X	X	X
• product reviews	X			
• pre-production builds	X	X	X	
• test operations	X	X		
• Engineering Change Orders	X	X		
• re-tooling	X			
• preventative maintenance			X	
• product holds	X	X		
• Closed Loop Corrective Action	X	X	X	X
• factory downtime	X	X	X	

COQ is not the cost of...

- doing normal business
- lost sales opportunities
- organizational inefficiency
- being slow
- capacity improvements
- IT tools

Figure 1 The definition of COQ at Dell

As COQ is defined as having an objective of creating a major cost reduction, the scope of COQ is broadly defined to include all that may affect Dell's costs related to defect management and prevention. The inclusion of software and services in the scope reflects the fact that a functioning piece of hardware may be inoperable at the customer's site if the software is not functioning or if services provided by Dell (i.e. installation services) are faulty.

As the quality delivered to the internal customer is likely to translate into quality delivered to the external customer, both internal and external customers were identified as part of COQ. And to reflect the many different types of outputs that organizations produce, the scope of COQ was defined to include not just material deliverables, but data as well. Examples of data that must be complete, accurate, and timely include work orders, Statements Of Requirements, procurement specifications, or Technical Support decision trees. Failure to produce quality data for internal and external customers can easily have an adverse effect on the cost of quality.

The causal table in the center of Figure 1 is intended to show that actions by the Services groups contribute less to the cause of the failure than do actions by the Design, Procurement and Manufacturing organizations. This is also reflected by the fact that approximately 90% of actual failures in the field are remedied by the first part dispatch that the Services group issues. That is, when a customer calls with a functional failure and the Services group sends the customer a replacement part or parts, that dispatch fails to solve the problem in only approximately 10% of the cases, resulting in a "Repeat Dispatch." A Repeat Dispatch leads to further costs of quality and damage to Dell's reputation and goodwill, as the customer must contact Dell again to request assistance. As will be discussed below, the Services group is very focused on reducing Repeat Dispatches.

The definition of COQ in Figure 1 is somewhat arbitrary. It could be argued that the cost of "organizational inefficiency" or the cost of "being slow" are part of Dell's COQ. It could also be argued that "product reviews" are part of Dell's cost of doing normal business and should not be included within the scope of the COQ project. It is precisely this ambiguity that prompted the need for clear bounds on the COQ effort. The definition of COQ put forth in Figure 1 is the establishment of those bounds.

Sizing up Dell's Cost Of Quality

When I first arrived at Dell, the COQ project was scoped to be a manufacturing-centric initiative. The intent was to identify those manufacturing expenditures which could be clearly categorized as the cost of conformance or the cost of non-conformance. Examples of cost of conformance categories would include test development, product inspection, and burn-in (a stress test that 100% of systems undergo prior to leaving the factory). Examples of cost of non-conformance categories would include rework, repair, and failure analysis. Together, the cost of conformance and the cost of non-conformance make up the Cost of Quality.

Although Dell's worldwide costs for maintaining and operating its manufacturing facilities are considerable, the costs that could be definitively identified as Cost of Quality were relatively small (less than 0.1% of total revenue). Benchmarking data from Motorola (below) indicates that Dell's Total Cost Of Quality is likely to be a far larger percentage of revenue. This suggests the need to approach COQ not from a manufacturing-centric perspective, but instead from a corporate-wide perspective. The corporate-wide financial evaluation shown in Figure 2 highlighted the largest opportunities for cost reduction.

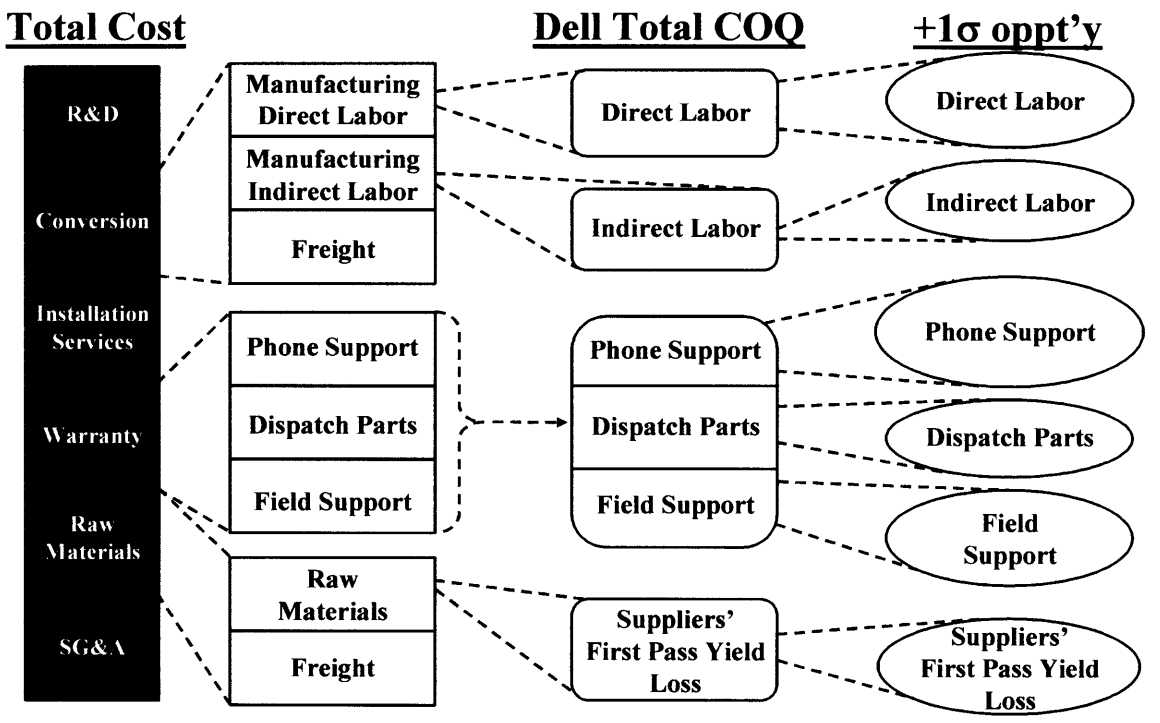


Figure 2 Dell's Total COQ opportunity

(actual data removed to protect the confidentiality of Dell financial information)

Figure 2 is a breakdown of Dell's total costs for FY'04, corresponding with a reported revenue of $41.4B for FY'04 (Dell, Inc. 10-K filing with the SEC, 4/12/04). These costs can be broadly broken into six categories, as shown in Figure 2. "R&D" reflects costs associated with product development, design, and research. "Conversion" reflects the costs associated with converting raw materials into finished goods and delivering those finished good to the customer. Conversion is broken into costs associated with direct labor (working on the product in the factory), indirect labor (engineering support for the factory and capital equipment), and freight of the products to the customer. "Installation Services" reflect the costs associated with providing services sold to the customer, such as product installation, preventative maintenance, or other service contracts. "Warranty" reflects the costs associated with fulfilling warranty obligations of real or perceived product failures in the field. Warranty is broken into costs associated with answering customer questions/concerns over the phone/internet (Phone Support), dispatching replacement parts to the customer in the field, or dispatching field support personnel to the customers' site. "Raw Materials" is simply the cost of all raw materials used to manufacture the product and the cost of freight for those raw materials. "SG&A" reflects the Sales, General & Administrative costs associated with maintaining a sales force, corporate offices, etc.

The "Dell Total COQ" column quantified and summarized the cost of managing failures in the lab, in the factory, and in the field, as well as the cost of testing and inspecting functional products/parts. With its actual data, Figure 2 successfully demonstrated that Dell's COQ is significant, that a reasonable improvement in COQ would provide the company with a significant cost savings opportunity, and that the largest opportunities lie in reducing costs associated with Phone Support, Parts Dispatch, and Field Support. The far right column titled "+1σ oppt'y" is discussed below in the "Dell's Cost Of Quality Opportunity" section.

While Figure 2 identified the largest COQ opportunities, Figure 1 was necessary to ensure that the Services group, which is responsible for Parts Dispatch, Field Service, and Phone Support, not be held accountable, in isolation, for achieving these targeted cost reductions. While the Services group plays an instrumental role in reducing COQ, little can be achieved without partnership and leadership by the Design, Materials, and Manufacturing groups.

The "5 Sigma" supplier

Many of Dell's suppliers assert that they are today at 5σ quality levels and, for some suppliers' products, the incoming defect rate observed at Dell is in fact at or near the 5σ quality level (233 defects per million, or dpm). However, even for these suppliers, the rolling throughput yield in their factory is less than the 99.98% which corresponds to 233 dpm. This is because it the incoming quality level seen at Dell is representative of the integrity of the supplier's final inspection, not the supplier's manufacturing process control. For example, imagine the following hypothetical supplier of widgets to Dell as illustrated in Figure 3:

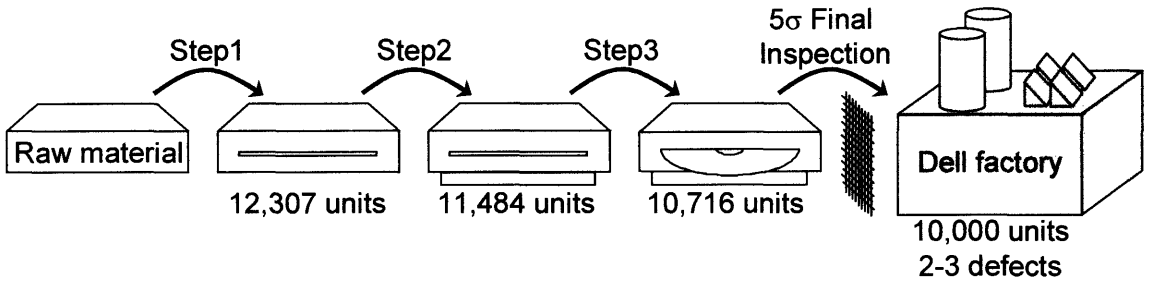


Figure 3 A theoretical supplier to Dell with 3σ process capability and 5σ final inspection

In Figure 3, Dell orders and receives 10,000 widgets from a supplier. When those 10,000 widgets arrive at Dell, there are 2-3 defects and 9,997-9,998 acceptable widgets. Dell perceives the supplier to be at a 5σ quality level, as Dell sees only 200-300 dpm from the supplier. However, this is reflective only of the quality level associated with the supplier's final inspection. The supplier's final inspection is sufficiently robust to identify all of the defects, save 2 or 3 which escape to Dell's factory. Assume that all defects at this theoretical widget supplier result in scrap (i.e. there is no rework opportunity for this product). If this supplier has 3σ process capability (corresponding to 66,810dpm) for its 3 serial manufacturing steps, the supplier would have started manufacturing 12,307 units to eventually yield the 10,000 units which would have passed the final inspection. Even though this supplier is shipping Dell a widget that is apparently at a 5σ quality level, there is a significant Cost Of Quality associated with the supplier's scrap resulting from its rolling throughput yield. This Cost Of Quality is not immediately visible to Dell, as it is hidden within the purchase price from the supplier. However, in this simplified example, the supplier began production of 23% more widgets than were finally delivered to Dell. This fallout is necessarily reflected in the purchase price to the customer; therefore, Dell is paying as much as 23% more than would be paid for widgets from a defect-free supplier manufacturing process.

It is also possible that the manufacturing process for these widgets is most efficient with the end-of-line testing shown in Figure 3 and that the costs necessary to reduce in-process defects would exceed the benefits achieved via reduced rework and scrap. If this is the case, efforts to reduce in-process defects may in fact add cost to the widgets.

Obviously, Figure 3 is a gross simplification of the effect of rolling throughput yield at a supplier. A more realistic scenario is that of a supplier with far more process steps, each with a yield in excess of the 3σ quality level assumed for Figure 3. Imagine instead that a supplier has 20 serial process steps, each with 4σ quality level (corresponding to 99.38% yield or 6,210dpm). The compound effect of these serial process steps is an 88.3% yield (99.38% yield for each of 20 consecutive process steps results in a rolling throughput yield of $99.38\%^{20} = 88.3\%$). Assuming that 2/3 of the defects identified in the supplier's manufacturing process can be reworked, touched up, or repaired, then only 1/3 of the defects identified would result in scrap costs. This would produce ~4% scrap costs (1/3 of the 11.7% fallout) in addition to costs associated with the rework, touch up, or repair costs. If such a 4% scrap cost were applied across all of Dell's expenditures for raw materials, this scrap would add up to a significant COQ hidden in the purchase price of those materials. The bubble shown in Figure 2 as "Suppliers' First Pass Yield Loss" is intended to represent these hidden costs.

Of course, even if all of Dell's suppliers deliver 5σ quality levels for the components that they provide, the compound effect at Dell's factories can be significant. For example, if 50 components (including packaging material, software, manuals, etc) are used in the manufacturing of a product and each of these 50 components is supplied at a 5σ quality level, the compound effect on the product is ~11,600dpm, or 1.16% failure rate. So, in addition to the hidden costs associated with rolling throughput yield that may exist at the suppliers' sites, Dell experiences very visible quality costs in the Dell factory resulting from the compound effect of the subcomponents' defect rates.

Dell's Cost Of Quality Opportunity

The far right column in Figure 2 is intended to size the COQ reduction opportunity that Dell could reasonably aim for in a three-year initiative (FY'05-FY'07). The COQ reduction opportunity was derived from the belief among Dell Executives that it would be a reasonable goal for Dell to incrementally improve its quality performance by 1 Sigma from its current quality level, consistent with other continuous improvement goals at Dell. This is not to be confused with each organization performing its role at a quality level improved by 1 Sigma.

To illustrate the difference between the COQ goal of improving all Dell quality level by 1 Sigma versus improving each organization's quality level by 1 Sigma, consider the Technical Support organization. It is the responsibility of the Technical Support organization to answer phone calls and e-mails from customers who believe they have a problem with a Dell product, to ascertain the cause of the customers' real or perceived problem, and to determine the most efficient solution for the customer that provides a satisfactory resolution in the eyes of the customer and costs Dell the least amount of money. Today, the Technical Support organization strives to improve its On-Time, First-Time Fix (OTFTF), which measures both the accuracy of the diagnosis of customers' problems and the timeliness of the solution provided. A repeat dispatch occurs when a component is dispatched to a customer to remedy a problem and the component dispatched fails to fix the customer's problem. There are many initiatives in the Technical Support organization targeting Repeat Dispatch Reduction (RDR). An internal assessment of the RDR opportunity indicates that planned reductions in repeat dispatches will provide Dell with significant savings. However, RDR focuses on defect management, not defect prevention. While it is certainly a valuable exercise to reduce expenditures via RDR activities, the savings anticipated by RDR is less than 6% of the total spent by Dell for all part Dispatches across the company in FY'04. While it may be reasonable to expect the Technical Support organization to reduce Repeat Dispatches through improved diagnostics, it is unreasonable to

expect that organization alone to prevent the field defect and thereby eliminate the need for the part dispatch. An effort to prevent defects must strive to find the source of the defect and eliminate that defect source. It is possible that the root cause of the defect resides within the control of the Technical Support organization. However, it is more likely that the root cause of the defect resides within the variation of the processes used by the Design, Materials, or Manufacturing organizations. This is reflected by the relatively small value of the savings that RDR is expected to yield.

For each area in Figure 2, an analysis was performed to quantify the benefit that would result if the overall field failure rate were improved by ~1σ. While the actual data is not shown here, the value the "Dell Total COQ" column proved to be a significantly large number. The far right column in Figure 2, indicating that the opportunity resulting from a 1σ improvement in overall product defect rates, added up to ~40% of the Total COQ number. This too was a significantly large monetary value. These two numbers proved to be somewhat controversial. Surprisingly, however, the controversy centered on the belief by some that these numbers understate the total COQ that Dell incurs. Some believed that Dell's Total COQ could be as much as 10 times larger that I had calculated, reflecting costs associated with performing any task in an inefficient or redundant manner. In theory, Dell's Total COQ might actually be considerably larger than I had stated, however, it was agreed that it would be difficult to concretely quantify the costs associated with inefficiencies or redundancies. By stating only the lower bound of the COQ opportunity, COQ could then be presented in a more defensible manner and would then encourage other groups to participate in reducing COQ as they discover previously unstated pools of COQ money.

Comparing Dell's COQ with Motorola's COPQ

One reason that that some Dell Executives believe that Dell's COQ opportunity is larger than was stated on Figure 2 is benchmarking data collected from Motorola. Motorola's test hardware division, responsible for manufacturing Printed Circuit Board Assemblies (PCBA's) and systems housing those PCBA's, underwent a 12 year initiative to reduce their Cost Of Poor Quality (COPQ) from 1986 to 1997. Motorola's definition of COPQ included all costs associated with inspection, test, rework, repair, scrap, and warranty. To ensure that these costs were tracked consistently year-over-year, Motorola established an internal-only accounting system that tracked the company's expenditures in these areas. This system was subject to internal audits and executives' pay was linked to reductions in Motorola's expenditures for the Cost Of Poor Quality categories (Miscynski interview). From 1986 to 1997, Motorola successfully reduced the COPQ from ~14.5% of total sales revenue to ~5.5% of total sales revenue.

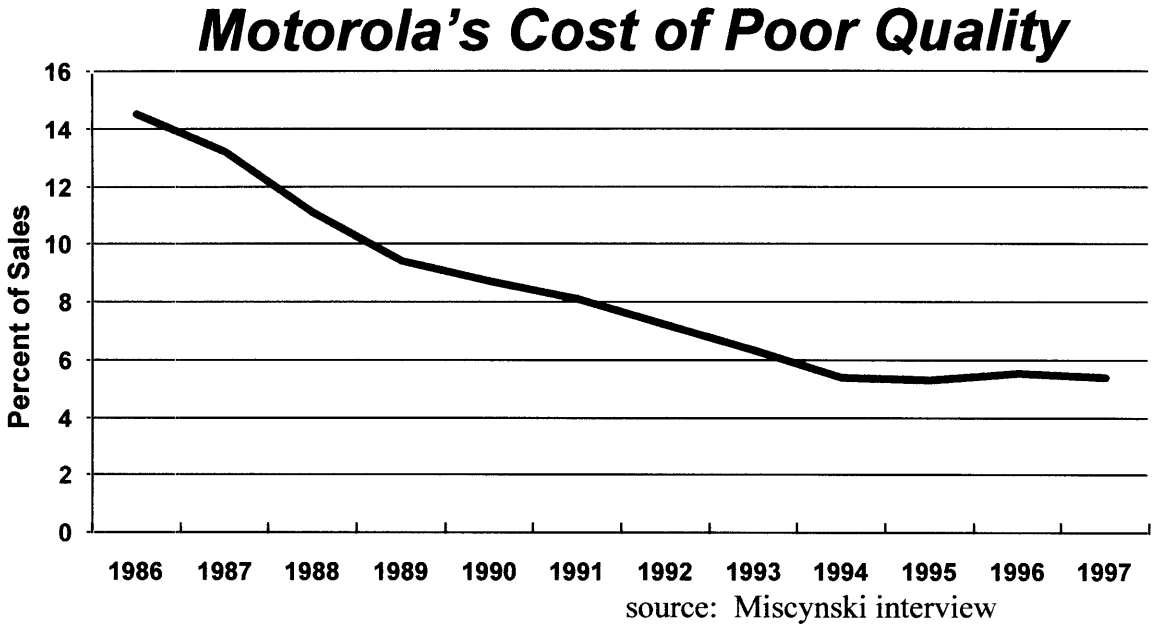


Figure 4 Motorola's Cost Of Poor Quality

By comparison, Dell's Total COQ for FY'04 is much less than Motorola's COPQ in 1997. There are at least three possible explanations for Dell's relatively small COQ. The first possible explanation is that Dell simply has better quality systems than Motorola, allowing Dell in 2003 to achieve a lower COQ than Motorola was able to achieve after a 12-year focused effort. The second possible explanation is that Dell in 2003 is utilizing the same industry standard component technologies that were used in Motorola's test hardware in 1997. Under this explanation, Dell essentially "rode the wave" of an industry-wide improvement in the quality of sub-component technologies. This explanation would be consistent with Dell's strategy of "leveraging industry standards" (Soul of Dell, 4). A third possible explanation is that Dell's COQ is not measured in the same way as Motorola's COPQ. Although both organizations use similar component technologies, the manufacturing processes differ substantially between Dell and Motorola's test equipment division. Where Motorola's test equipment division created PCBA's through a process where electrical components were soldered to a bare Printed Circuit Board (PCB), Dell purchases fully functioning and tested PCBA's from its suppliers. Where scrap and rework costs associated with converting PCB's into PCBA's would be captured in Motorola's COPQ, it would be hidden in the purchase price at Dell. With this explanation, it could be argued that some percentage of the money that Dell spent in FY'04 on raw materials was actually spent to cover the suppliers' scrap and rework costs and was therefore a contributor to Dell's COQ.

CHAPTER 3 – HOW IS COQ ANY DIFFERENT FROM WHAT WE ALREADY DO?

This chapter shows how the COQ effort differs from Dell's existing Field Incident Rate reduction activities, describes the process of root cause determination, and evaluates five existing sources of defect data at Dell. The evaluation of these existing sources of defect data will demonstrate the absence of a statistically-representative, causal data source to guide the COQ project.

Reducing Dell's Field Incident Rate

The most straightforward criticism of COQ is that it is not immediately evident how COQ differs from Dell's already existing quality improvement initiatives. For many years, Dell has been working on reducing the company's Field Incident Rate (FIR), which is a measure of Dell's product quality as observed by the customer. Is COQ just "FIR Reduction" with a new title?

To answer this question, it is necessary to examine the typical FIR reduction process. To illustrate a hypothetical example, consider Dell's low-end PC sold into the Home & Home Office market segment (see Appendix 2). These low-end computers constitute one of the many platforms of products within a particular Line Of Business (LOB). Typically, a new product is launched two to four times each year for this platform, within this LOB. Each new product within this LOB is similar to the previous products, but is intended to include a "refresh" of product features to ensure that the product continues to align with consumer preferences. In addition to updating the product features with each successive product launch, a team of Customer Support Technicians and Engineers analyze the product's FIR and use the refresh as an opportunity to reduce the FIR of that product through specific quality improvement actions. Such actions might require moving the location of a component, changing the bend of a chassis dimension, or adding an electrical component to the circuit. These actions are intended to resolve a specific failure mode for a specific product. However, the product-specific actions fail to address the process breakdown that originally led to the failure.

Consider the following hypothetical example: Suppose that during a product refresh it is determined that it is necessary to add an additional capacitor to the LAN On Motherboard (LOM) circuit to eliminate a defect that has been observed on some units in the field. This action would certainly improve the FIR for the next product that is launched. This is a "find and fix" approach to managing quality and is a necessary activity to improve the quality of the next product. However, in addition to fixing the identified problem on this product, there is a fundamental process underlying this defect that should to be examined. Investigating further into this failure would indicate which process(es) failed to prevent this defect prior to product launch. Was the LOM circuit design/validation insufficient? Were components tested in the original circuit better than components seen in the product during high volume production? Is the impedance of the motherboard traces well-controlled by the printed circuit board supplier? Whatever the product-based solution (adding a capacitor to the LOM circuit), there is an underlying process-based solution that needs to be defined. Implementing a process-based solution may have far-reaching effects, as that process improvement will affect all products that rely upon that process. For example, if the additional capacitor is necessary to compensate for high variability in the trace impedance of the printed circuit board, it is possible that such high variability is affecting many other products. Or if the defect is the result of a gap in the design review process, that process gap may be causing defects in other products. Determining which underlying process allowed this failure to originally occur may lead to a process-based corrective action that solves problems occurring on many products, across many platforms, in many LOB's.

Such a process-based solution, albeit more time consuming to implement, may prove to have far-reaching benefits.

This is not to suggest that Dell exclusively focuses on product-based solutions, nor it this to suggest that a time-consuming, resource-intensive process-based solution is the appropriate course of action for every defect identified. However, Dell's strategic position of low-cost leadership has led Dell to one of the lowest overhead costs (as a percentage of revenue) in the computing industry. This, combined with Dell's direct-to-customer manufacturing model, has resulted in little time and few resources to dive deep into the process deficiencies behind problems.

In fact, a focus on FIR Reduction has the potential to negatively affect overall quality. Organizations which are measured by their ability to quickly improve FIR after a product has launched may wish for the initial FIR to be very high, thereby creating a FIR baseline from which improvement is less difficult. Just as purchasing organizations may privately prefer high initial component prices from suppliers, so that they may show large "cost savings" as they negotiate prices down from that baseline, design teams may privately prefer a higher initial FIR, so that they may show significant quality improvements over time. This is particularly an issue when promotions, salaries, or other incentives are directly linked to FIR improvement metrics. To combat this tendency, additional metrics are in place at Dell to evaluate intergenerational FIR, the comparison of initial FIR from a previously launched product to the initial FIR of the current product. A successful product introduction is then the combination of a quickly-decreasing FIR and an initial FIR that is lower than that of previous products. However, the dissimilarity (real or perceived) of previous products often makes the comparison of intergenerational FIR highly contentious. Increases in initial FIR can often be explained away with assertions of "increased product complexity" or "new technology introduction". Further, the establishment of an intergenerational FIR metric creates a disincentive for design teams to produce a product with dramatic improvement in quality, as that would become the expectation for all subsequent products. FIR Reduction initiatives, therefore, have the potential to encourage teams to seek controlled, incremental improvements in product quality and to discourage step-wise, dramatic improvements in product quality. This is especially the case if such improvements are perceived to be difficult to sustain for future products.

The above is not meant to suggest that any company's design teams are actively seeking to introduce product defects or that there is any conscious effort to undermine the quality of a product. Instead, these incentives simply guide the teams' investments of limited resources. With limited personnel, teams may elect to assign an engineer to product design first and product validation if s/he has time. Or a team may elect to conduct a robust qualification of a component and then choose to "paper qualify" a second supplier's equivalent component, relying on the fact that both suppliers have the same component specifications. It may be discovered only later that the first supplier's component, which was robustly qualified, actually performed far better than the specification and that the second supplier's component barely met the specification. This could lead to failures at the outer bounds of the specification, even though both suppliers' components meet the stated specifications.

Root Cause Determination

Solving a problem is often described as analogous to peeling an onion. On the surface, the symptom of the problem is clearly visible. Peeling the surface layer away by asking "Why is this symptom occurring?", it is possible to evaluate the layer beneath the symptom. Some would argue that it is necessary to ask "Why?" five times to truly get at the core of the onion, the "root

cause" of the problem (Shiba, 209). "Root Cause" is a phrase that is often bantered about when solving a problem, however, there is generally disagreement about what the term "root cause" means. For the purposes of this paper, I will define root cause as:

> that which, when removed, prevents a specific failure mode from ever occurring again

This definition is misleading in its simplicity. In fact, root cause analysis is anything but simple. How the problem is defined will often determine the narrowness or breadth of the root cause analysis. The experience and background of those performing the analysis is likely to significantly affect the outcome of the analysis. The availability of resources and the perceived severity of the problem will guide the root cause analysis to a product- or process-based solution. The incentives of the organization will determine the amount of time that employees are willing to invest in root cause analysis.

To be effective at root cause analysis, employees need a process which provides clear guidance as to when a problem should undergo analysis and when it should simply be fixed. Dell's factories have implemented a highly sophisticated, statistically-based system of triggers which tell factory engineers when a root cause analysis is necessary. These triggers automatically evaluate over 1,500 product-specific metrics daily, highlighting those metrics which have violated one of five statistically-determined rules. Those metrics which are highlighted as Out Of Control (OOC) or trending toward an OOC condition are discussed by a team of manufacturing engineers in a daily review. Because this process highlights any statistically-relevant changes, both positive and negative shifts in defect rates are reviewed. In some cases, an improvement in factory defect rates is highlighted and prompts the manufacturing team to investigate what has changed.

It is imperative that root cause analysis be reviewed in a team environment. With a broad constituency of team members, the team will invariably arrive at a different root cause than if the analysis had been performed by any one individual. Also, with individuals of multiple backgrounds assisting with the analysis, it is possible to arrive at a cheaper, quicker solution than would be pursued otherwise. To illustrate the perils of isolated root cause analysis, consider the following hypothetical example. Suppose that a failure(s) in the factory prompts a Manufacturing Engineer to investigate the root cause and that the Manufacturing Engineer determines that the root cause is a design issue. The Manufacturing Engineer then shows his/her analysis to Design Engineers who concur that the problem is in fact an issue in the design and determine that a solution can be incorporated into the next product revision some months in the future. The factory must continue to accommodate this failure until the new design is launched. However, if a team of engineers across multiple disciplines had worked together to develop and review the root cause analysis, it is possible that a Materials Engineer would have suggested a cheaper, easier-to-implement solution for this design problem. But in the hypothetical example above, no Materials Engineer was part of the process and therefore his/her knowledge was not incorporated into either the analysis of root cause or the determination of a solution.

Ideally, Root Cause analysis should be a collaborative exercise, seeking to find a process-based solution that permanently prevents the failure from occurring again.

Existing Sources of Failure Data

As with most companies, Dell has many sources of failure data. These data sources vary both in their depth of technical analysis and in their statistical robustness. Many sources of data

are sufficiently causal to identify the cause of a failure, but rarely are these data sources statistically representative of the failures that are occurring in the factory or in the field. Other data sources are statistically representative of the failures that are occurring in the field, but are lacking in sufficient detail to allow for technical analysis. To determine which types of failures contribute the most to Dell's COQ, it would be valuable to analyze a causal, statistically representative database of failures and to use that analysis to guide investments in defect reduction. As mentioned previously, it should not be Dell's objective to blindly reduce defect rates. Dell is already providing customers with failure rates that are competitive. Instead, Dell must reduce cost (and price), using improvements in failure rate as a cost reduction mechanism. Therefore, it is not sufficient to ask: "What is failing?" Instead, the question that must be asked is: "Reducing which failure would provide the largest opportunity to reduce cost?" Below is a brief examination of five primary sources of failure data at Dell, looking for data that will be both causal and statistically representative of the failures in the field, in an attempt to answer this second question.

Tech Support Logs

When a customer calls Dell with a technical problem, the call is routed to a support technician and the issue is logged into a service database (the Tech Support log). The technician assists the customer over the phone with diagnosis and, based on responses from the customer, provides the customer with software or hardware solutions as necessary to resolve the problem. As many of Dell's customers are home users of personal computers, much of the job of technician is to respond to perceived product failures by educating the customer on the technical usage of their Dell product. This is the case when customers have incorrect software settings or have purchased third-party software that requires a change in the configuration of their personal computer. In the case of actual product failures, customers are often lacking the technical expertise to accurately answer the questions that are asked by the technician. With no direct interaction with the product and less-than-ideal input from the customer, technicians face a daunting task in making an accurate diagnosis remotely. Impressively, Dell's support technicians accurately diagnose the real or perceived failure almost 90% of the time.

Each of these diagnoses is recorded in Dell's Tech Support logs, forming a statistically representative database of failures. However, due to the fact that the technician is not interacting with the failure in a hands-on manner, these Tech Support logs generally lack sufficient data to provide the design team with enough data to know if a detailed Failure Analysis (FA) is necessary. For example, it is common to find entries in the Tech Support logs such as:

1) NO PWR, BAD MB
2) NO VID, BAD MB
3) NO VID, BAD MEM

for three different failures in the field. [Here, PWR = "power", VID = "video", MB = "motherboard", and MEM = "memory".] In the case of the first failure, "NO PWR, BAD MB", the customer indicates that the product would not turn on. After working with the customer to ensure that it is plugged in to a functioning electrical outlet, that the electrical cord is not damaged, etc. the technician determines that the issue was in fact a real product failure. However, further diagnosis is difficult when the product will not power up and will not respond in any way. Based on a decision tree provided by the Design group indicating that the most likely point of failure was the motherboard, the technician dispatches a replacement motherboard

to the customer. If this fails to solve the customer's issue, the customer calls Dell a second time and the next action taken is logged as a "repeat dispatch". However, if sending a replacement motherboard solves the customer's issue, the Tech Support log does not provide sufficient level of detail to determine what about the motherboard was defective. The possible causes behind this "BAD MB" are many and varied, ranging from customer-induced damage to shipping-related damage to poor design to poor manufacturing to poor component reliability. While the Tech Support logs are voluminous and are closely correlated with the failures in the field, they are not capable of providing the kind of causal data that is necessary to implement a systematic solution. It is, however, possible to analyze the symptom data found in the Tech Support logs and to use this data as a measure of the result that follows from a change. For example, if a change to the product or manufacturing process is implemented with the intent of reducing failures in the field, the Tech Support logs may be used to validate a reduction in the symptom which corresponds with that change.

	Symptom/Cause	Statistically representative?
Tech Support logs	Symptoms	YES
Supplier FA data	Causes	NO
ARC FA data	Both	NO
Design Engineering FA data	Causes	NO
Lessons Learned data	Causes	NO

Figure 5 Existing sources of failure data at Dell

Supplier FA data

All the materials that are returned from customers in the field are sent to Dell's original supplier for FA. In addition to the lengthy delay between sending a failed component to the supplier and in receiving FA, the FA data is generally aggregated by the supplier and disassociated from the symptoms. Further, a significant percentage of the failed components sent to Dell's suppliers for FA are determined to be CND (Can Not Duplicate). Understanding that most suppliers' primary motivation in performing FA is to demonstrate that the failure is not their fault, it is not surprising that many of the FA's result in a CND finding.

It is possible that the "defective" component returned from the field was in fact a good, functional part. This may occur if the failure is misdiagnosed by the Support Technician, but will also occur if multiple parts are sent to the customer to over-correct for an inability to precisely diagnose the failing component. For example, in the case of the "NO VID, BAD MEM" failure, the support technician successfully determines that the symptom (no video) was caused by a failure in the computer's random access memory (RAM). However, to precisely determine which of the four RAM modules in the computer is defective would require discretely testing all four modules. Rather than risking the possibility of a repeat dispatch, the technician sends the customer four new RAM modules. It is very likely that three of these four RAM modules will be determined by the supplier to be CND, as would be expected.

But a significant limitation on the ability of supplier FA to provide meaningful analysis is that the supplier can only analyze that which was sent to them. That is, the suppliers' analysis of a single component fails to evaluate any interaction effects that may have contributed to the failure. For example, in the case of the "NO VID, BAD MB" failure in the above Tech Support

log, it is possible that replacing the motherboard corrected the video problem, but that the motherboard itself was not defective. This can occur when the failure is not a result of a single defective component, but instead the result of a defective interaction of multiple components. The NO VID problem may have been a result of the interaction between a marginally performing motherboard and a marginally performing graphics card, neither of which fails to meet its component specification, but fail in combination. Replacing either the marginal motherboard or the marginal graphics card with a nominally performing component is likely to have corrected the failure, but neither the motherboard nor the graphics card would be found to be failing when evaluated by their respective suppliers.

Most computer manufacturers provide their suppliers with test beds that simulate the product, such that the supplier may perform FA both on the component in isolation and on the component in its interaction. This can be effective in identifying interaction effect failures. However, even these test beds, which are intentionally designed to represent a nominal system in an average customer environment, fail to address the situation where multiple marginal components are interacting. To attempt to create a discrete test bed for every possible permutation of marginal components would be excessively costly. To address the interaction of multiple marginal components, it would be less costly for suppliers to provide Dell with continuous distribution data for critical parameters and not simply discrete pass/fail evaluations. This distribution data could then be analyzed to determine which bounds of the specification are most likely to lead to an interaction effect failure.

ARC FA data

Another possible source of failure data may be found at Dell's Americas Remanufacturing Center (ARC), where whole computer systems are returned from the field in their entirety. ARC's primary objective is to ensure that computer systems are in working condition and return them to the field as quickly as possible as a refurbished product. Many of the systems returned to ARC are simply products that the customer refused, either at the time of delivery or within 30 days of receipt. As such, many computer systems that ARC receives are completely functional when they arrive and are immediately re-sold as a refurbished product. Economically, this is a time-critical function, as the value of already-configured computer systems diminishes daily. When computer systems are returned to ARC as a result of a failure in the field, the data collected at ARC is valuable for causal failure analysis only in specific circumstances. There are many reasons why this is so.

First, upon receipt of a computer system from the field, one of the first actions that ARC takes is to erase all data off the hard disk drive (HDD) and to re-burn the factory image onto the HDD. This process completely replaces the operating system (OS) as well as any applications that were stored on the HDD. If the failure in the field was a result of a corrupt OS or other software deficiency, this process fixes the problem without any diagnosis or documentation of the problem.

Second, the testing procedure used by ARC to determine if a product is functional and ready to be shipped to a new customer is the same procedure as that which is used in the high-volume manufacturing facility. If the failure that caused the computer system to be returned to ARC was a result of an insufficiency in the test procedure (a "test hole") at the original manufacturing facility, that same test hole would cause ARC to ship that same failure to another customer.

Third, failure analysis at ARC is an exception-based process. For some products that are in their early months of production, ARC will perform FA on a large percentage of the computer systems that are received. FA will also be performed when the ARC manufacturing technicians

identify a recurring failure. This exception-based FA procedure is a cost-effective way to utilize limited resources, but does not produce a statistically representative picture of the failures in the field.

Fourth, ARC's failure analysis data is dynamic in nature. When the FA Technicians see a failure mode that is repeating, they will typically provide instruction to the ARC manufacturing employees so that they may correct this failure themselves. Once ARC manufacturing employees begin to correct the failure themselves, the failures no longer are routed to the FA Technicians and the failures are no longer recorded in the ARC failure analysis database. While this process helps to make ARC more efficient as a revenue-generating manufacturing facility, it compromises the statistical validity of the FA database.

Finally, ARC's failure analysis capabilities are limited. For mechanical failures, it is sometimes possible for the FA Technicians to arrive at a detailed description of the failure mode and a first-order causal explanation. With some additional work, it may be possible to take these mechanical evaluations and determine a process-based solution that would prevent the failure in the future. However, for electrical or software failures, ARC is less equipped to provide causal explanations, often resulting in symptom data such "NO PWR, BAD MB" similar to those seen in the Tech Support logs.

All of the above contributes to ARC's success as a Remanufacturing Center and enables ARC to be very efficient at turning returned computer systems into revenue as refurbished products. In some cases, the ARC failure analysis data is effectively used to implement design or manufacturing process changes to reduce the incidence of a particular failure. However, the data collected by ARC is lacking sufficient detail and is not sufficiently representative of failures in the field to be used to guide the COQ effort.

Design Engineering FA data

When Tech Support logs, Supplier FA, or ARC FA data indicate that there is a significant issue that requires the attention of Design Engineering, defective components or entire systems are sent to the Design Engineering groups for detailed failure analysis. These analyses are highly focused on a specific problem, providing detailed and thorough evaluation. However, this data too is not statistically representative of the failures occurring in the field. For example, suppose that the Tech Support logs indicate that a BIOS update has been required to fix a problem observed with a number of Dell servers in the field. This may prompt the Design Engineering group responsible for software to collect a number of defective systems (prior to the BIOS update) to evaluate the failure and determine its root cause. Suppose that the investigation shows that only 2% of the servers are requiring a BIOS update, but all of those requiring an update are of the same manufacturing date code. Further investigation may point to a process breakdown in distributing the latest BIOS revision to the factory in a timely manner. This would then lead to a process improvement for BIOS revision updates. While this is precisely the kind of failure analysis, root cause determination, and process-based solutions that will improve Dell's failure rates, this does not provide data to determine whether or not this failure mode is a significant or insignificant percentage of Dell's total failure rate or total COQ.

Lessons Learned data

In an attempt to categorize and aggregate Design issues that have resulted in product failures, Dell has developed a database of lessons learned. This Lessons Learned database documents the symptom of the failure, the technical root cause, the process root cause (which process was deficient in preventing this failure), the impact to Dell's failure rates, the impact to Dell's

finances, the responsible organization, and the corrective action to systematically prevent the failure from occurring on future product designs. As a new product is developed, the design team routinely reviews the Lessons Learned database to ensure that the new product design does not repeat past failures. As organizations "institutionalize" the lessons, they are removed from the Lessons Learned database and put in an archive. Institutionalizing a lesson requires that the design process be changed in such a way that it is not possible to repeat the failure, even if the personnel were to change. That is, an institutionalized lesson is not dependent upon tribal knowledge or training of employees; the lesson is built into the design process in such a way that it cannot be violated. While not perfect, the Lessons Learned database is clearly the most comprehensive source of causal failure data at Dell. And this process of institutionalizing lessons results in fundamental changes to the design process that improves the failure rates of many products.

In an attempt to determine which processes were contributing most significantly to Dell's COQ, I evaluated 828 active and archived Lessons Learned, categorizing each lesson into the process failure modes listed in Appendix 6. The failure modes can be aggregated into the areas listed in Figure 6.

All Lessons Learned

Change Management	xx
Design	xx
Materials	xx
Miscommunication	xx
Other	xx
Validation	xx
Total	828

Figure 6 Categorization of 828 active & retired Lessons Learned

(data has been aggregated & rearranged to protect the confidentiality of Dell's quality information)

From this rearranged categorization of Lessons Learned, one may conclude that the top area (hypothetically change management) is the largest contributor to Dell's failure rates. However, it is very possible that the organization managing change is simply very diligent in entering data into the Lessons Learned database or that the change management team has been using the Lessons Learned database for a longer period of time and has therefore had more opportunity to enter data into the database. In fact, these are precisely the reasons that "Change Management" is at the top of Figure 6. While the Lessons Learned database is very thorough in its technical evaluation of failures, it is not statistically representative of the failures in the field. Also, the Lessons Learned process is, today, limited in scope to technical hardware and software failures. It is possible that failures resulting from other, non-functional areas such as order processing, may be contributing significantly to Dell's COQ. For these reasons, the Lessons Learned database cannot be used as a statistically representative guide for the COQ effort.

Ideal data

If the primary objective of the COQ project were to reduce failure rates in the field, any one of the five sources of failure data would have been sufficient to identify actions that could help to accomplish that objective. However, COQ is first and foremost a cost-reduction project intended to assist Dell in reaching its OpEx targets. As such, it is imperative that the COQ project be

guided toward those actions which will reduce Dell's costs the most while incurring the least additional expenditures. That is, the primary data challenge for the COQ project is to determine return on investment (ROI) and pursue those actions with the most attractive return:investment ratio. For the reasons above, none of these five sources of failure data are sufficient to guide the COQ project.

Ideally, a statistically representative, causal database of failures is required to guide the COQ project. Such a database could be used to determine which causes were contributing most significantly to Dell's COQ. Once that is determined, it would be possible to evaluate the investment needed to address those causes. Then, these investments could be compared with the expected improvement in COQ to result in an estimated ROI. The outcome of such an analysis may prove to be surprising. It is possible that small investments in some causal areas would lead to disproportionate reductions in Dell's COQ. It is also possible that the causal areas that are the focus of Dell's current failure rate improvement projects may prove to have a poor ROI due to either a lower than expected return or a higher than expected investment.

So, how could Dell develop such an ideal database? One possible method would be to collect field data with a statistically significant sample size to determine causes for each real or perceived failure and to determine the cost to Dell that resulted from that real or perceived failure. Such a field data collection exercise may entail capturing the entire computer system for hundreds or even thousands of customers to perform interaction effect analyses and to evaluate the failure as experienced by the customer. Obviously, field data collection of this magnitude would be very costly. In keeping with the spirit of COQ, it would be necessary to demonstrate a positive ROI to justify an investment in such an effort.

CHAPTER 4 – MOVING COQ FROM THEORY TO TACTICS

After identifying the cost savings that could be realized through a COQ effort, illustrating the differences between COQ and previous failure reduction initiatives, and showing a fundamental lack of statistically representative causal data to guide the COQ project, I found myself with broad executive support for COQ and no clear plan of action. Some executives asserted that the gross gaps in process which led to Dell's COQ were obvious and well-known. After hearing my status in the July 2003 World Wide Quality Forum (WWQF), these executives argued against expending resources to pursue ideal data via a field data collection exercise, as it was generally agreed that such an effort would be too expensive to justify. It was decided that I would instead lead a number of brainstorming teams to document what was "obviously broken."

We already know what is broken

In a number of brainstorming meetings with approximately 20 employees across Materials, Design, Manufacturing, and Services, it became clear that there was no general consensus on what was "broken." I intentionally held parallel meetings with employees from a variety of functional areas and at various management and individual contributor roles, in an attempt to cast a wide net and identify common findings between the multiple brainstorming discussions. In establishing two separate meeting groups, I was attempting to sample independent data from each of the cross-functional teams. It was my hope that a few process areas would receive consistent focus in these meetings, providing some guidance for further investigation. But in fact, there proved to be little overlap between the conclusions each brainstorming meeting arrived at. After the brainstorming was completed, I shared the top conclusions across the participants and observed significant disagreement about the validity of the conclusions. The participants from each team did not agree with the other team's conclusions.

In these brainstorming discussions, some individuals' deeply held underlying assumptions became obvious. For example, some in Manufacturing argued that any failure, for any reason, was a Design issue. Others in Design asserted that the largest failure expense was a result of misdiagnosing failures by the Services group, citing the prevalence of CND's. Others in Services claimed that, because every component procured by Dell is an industry standard component, if it failed, it must be a supplier variability problem. Still others claimed that product failures were primarily a result of insufficient resources being assigned to project teams, blaming Management for a "short-sighted" focus on OpEx. Obviously, these claims created much defensiveness among the brainstorming team and were not very effective in determining which process areas would provide the most significant COQ reductions. Some employees became concerned that the COQ project was attempting to find an organization that could be blamed for every product failure. *However, the brainstorming meetings did prove effective in creating awareness of the issues that COQ was intending to address.* Few people were aware of the large financial opportunity presented by COQ and the large gap between understanding the costs of quality and the causes of quality. However, due to the deeply held and widely varied assumptions across the company, the brainstorming meetings were ineffective at defining possible solutions. Clearly, to be successful, the COQ project would need to move away from people's accusations and assumptions and toward something more tangible. The challenge was to do this without a costly investment in data collection.

After approximately one month of brainstorming meetings and numerous one-on-one meetings with individuals throughout Materials, Design, Services, and Manufacturing, I revealed the findings in the August 2003 WWQF. After reviewing both direct data and aggregate data

from the brainstorming and individual meetings, I noted that employees' conclusions about the primary causes of defects were both inconsistent and laden with (often faulty) assumptions, such as the belief that CND's were 100% attributable to misdiagnosis of the failure. I again suggested a data collection experiment to arrive at statistically representative causal data for Dell's total Cost Of Quality. One Executive asked me what the cost of such a field data collection exercise would likely be. Prepared for this question, I responded with an estimated cost, resource requirement, and time to completion. While not millions of dollars, the estimate represented a significant cost expenditure. I further indicated that to pursue this path likely meant repeating the experiment on an annual basis to demonstrate that the top causal areas were in fact improving and to re-set actions towards new Top Cause areas. My presentation was scheduled for only 30 minutes of the WWQF. However, the discussion continued for nearly two hours. No one appeared willing to say that they were uncommitted to COQ, but neither was anyone willing to commit the dollars necessary for an expensive data collection exercise in the field. The meeting culminated with an acknowledgement that product defects resulted primarily as a result of process variability. From this, it was concluded that identifying and minimizing the major sources of variability in each process would significantly reduce Dell's COQ.

After some additional discussion, there was widespread agreement that the next WWQF should be an all-day meeting to review the process variability of each organization. I was charged with making this happen. Shortly after this meeting, I discovered that despite the agreement to pursue this direction, there was much confusion about what 'reviewing process variability' meant and there remained significant concern that the COQ project was an effort to find the department that is 'culpable' for all of Dell's defects.

I walked away from the August WWQF with the responsibility to schedule an all-day process review and make it successful, yet I still harbored serious concerns about our direction:

> Everyone agreed to analyze his process, identify the control points, and present in an all-day offsite. While it is certainly a valuable activity to understand process variability better, I'm afraid that we're running without knowing if we're running in a direction that will actually reduce the company's COQ. What if our assumption (which was not based on data) is flawed? Is it possible that a reduction in process variability is not only difficult to achieve but is not sufficient to reduce COQ? It appears that, rather than focusing efforts in a single direction, we're taking a shotgun approach (to improve every area's process variability).
>
> 8/27/03 personal notes

Prior to the October 8 all-day meeting, I scheduled one-on-one meetings with Directors and VP's across Services, Materials, Manufacturing and Design to describe the expectations for process mapping, to reassure everyone that COQ was not a disguised witch hunt, and to develop the process map for the Manufacturing organization.

Process mapping

To identify opportunities for process variability in each area, I developed a conceptual model (Figure 7) for process-mapping and reviewed this model with managers throughout the company. While this is a highly simplified model, it was intended to highlight the areas that may lack sufficient control mechanisms, while avoiding tendencies to produce voluminous process flowcharts that would be overly detailed and not conducive to a cross-organizational discussion.

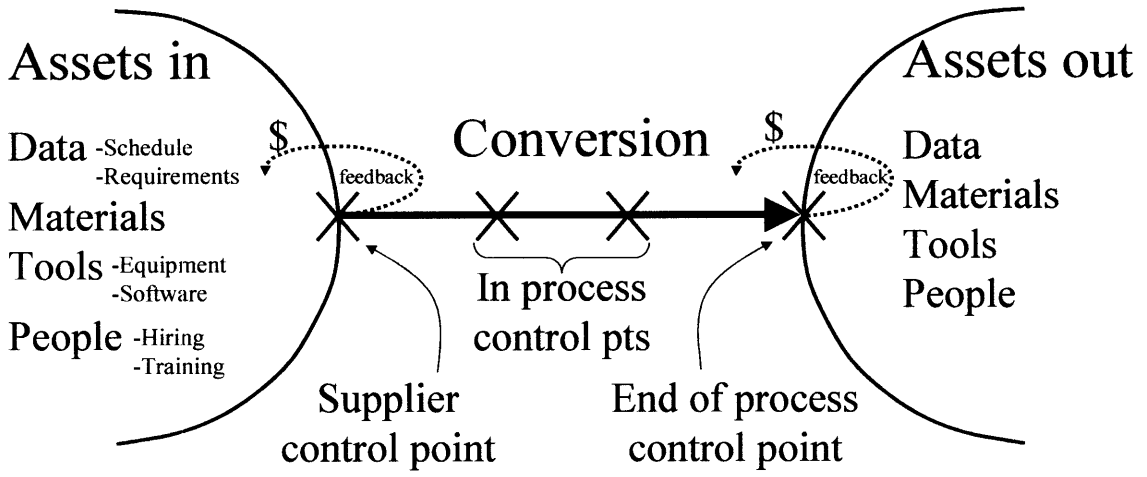


Figure 7 Process-mapping simplified example

At the highest level, the notion behind Figure 7 is that every organization's process begins with some inputs (assets) and that those inputs are converted into outputs that are delivered to internal or external customers. To illustrate some of the subtleties of this model, consider the design process.

The design process begins with Data inputs, primarily from marketing organizations, such as a Statement of Requirements (SOR) and a time-to-market schedule. The design process also requires Materials for prototype evaluations and product testing, software Tools for analyzing the design, lab equipment Tools for evaluating the design, and skilled People, sufficiently trained. Each of these inputs can vary in their completeness, timeliness, and accuracy. The variability of these inputs can have significant impact on the ability of the Design organization to efficiently convert those inputs into a complete, timely, and accurate design. As a hypothetical example, if the SOR from marketing is late or incomplete, the design organization may have significant difficulty changing its in-process design at a later date when the SOR is updated. For each of the critical inputs to the design process, there should be a mechanism for determining if that input meets the needs of the design organization and a feedback loop to the supplier of that input.

It is also important that the feedback be communicated in a language that is understandable to the supplier. In the hypothetical example, if the design organization simply expressed its angst and dissatisfaction to the marketing organization for a late or incomplete SOR, the marketing organization may empathize with the design group but may still be unwilling to invest the resources necessary to improve the SOR process. If instead the design organization communicates its dissatisfaction to the marketing organization by showing the expenses that were incurred as a result of the late or incomplete SOR, then the marketing organization may determine that it is cost-effective to invest the resources necessary to improve the SOR process and avoid future design expenses.

The first task for this process-mapping exercise was for each organization to determine the relevant high-level inputs, to identify which of those inputs were lacking sufficient control measurements, and to determine which feedback loops were lacking. This was termed the Supplier Control Point.

After analyzing the inputs to a process, the next exercise was to determine if there were sufficient in-process control points to determine if and when the process is drifting out of control.

In a manufacturing operation, it is possible to exclusively monitor the factory's end-of-process control points, i.e. defect rates during final testing. However, a more effective control system would employ in-process controls to determine if and when a given process is drifting out of its allowable range. Such in-process controls allow for trends to be identified and troubles corrected before the product begins failing at an end-of-process test. While in-process controls are difficult to implement in a manufacturing environment, they are even more challenging to implement for organizations such as Design. It is certainly possible to measure the end-of-process performance of the design organization by stressing early prototypes with aggressive testing. However, it is much less clear how a design organization may establish in-process control points to determine trends and out of control conditions early in the design process.

After evaluating the inputs to the process and the in-process controls, the final exercise was to evaluate the end-of-process controls and the feedback loops with internal and external customers. Perhaps the most challenging question any supplier must answer is: "How do I know that I am meeting the needs of my customers?" To have functional feedback loops with customers, it is necessary to have a clear understanding of the customers' needs, as well as timely metrics indicating performance to those needs. And again, the feedback loop must be in a common language that the supplier and customer can both understand, typically money. Given the opportunity, the customer will invariably ask for an expensive change to the suppliers' process. Only if this is communicated in the form of a financial benefit may the supplier weigh that financial benefit against the cost necessary to satisfy the customer's requests.

It is all too easy for a supplier to place the burden of feedback on the customer, especially when the customer is another organization within the company. But to wait for a customer to complain is an obviously inefficient feedback process. Each organization should be tasked with ensuring that their outputs are meeting the needs of the customer and that the feedback loops are robust. The burden of feedback should not be placed solely on the customer.

In evaluating the outputs that an organization produces, it is likely that an organization will underestimate the varied outputs that it produces. It is possible for a manufacturing organization to focus on the timely, functional, low-cost Materials that it produces for the external customer. Such a narrow view of manufacturing outputs fails to include the Data, Tools, and trained People that the manufacturing organization also produces for internal customers.

After working closely with managers across the company over the course of approximately six weeks, the Design, Materials, and Manufacturing organizations were prepared to present their high-level process maps and to discuss opportunities for variability reduction in their processes. The Services organization, still very concerned that the entire COQ effort was a disguised attempt to 'blame' the Services organization, indicated that it would not be prepared to present a process map at the all-day meeting.

The all-day meeting to review process maps brought together four VP's and six Directors from across the company. It began with a reminder from the VP of Quality that the purpose of meeting was to work collaboratively across the company. After this reminder and an inspirational introduction by the VP of Operations, the meeting proceeded in a very collaborative fashion. Each organization, beginning with Materials, presented its process in a candid fashion and the comments/questions posed by the audience were extremely constructive. At no point did the discussion turn accusatory or attempt to place blame on any organization. While this is certainly in large part a result of the introductory discussions described above, credit should also be placed on a courageous Director of Materials who began the process-mapping review with a self-critical, continuous improvement approach. By openly highlighting known process gaps and deficiencies in controls of variability, the materials organization eliminated the need for others to

find weaknesses in the materials process. Instead, the other Executives offered suggestions for improvement and proposals for cross-organization engagement to lessen the deficiencies identified. Following the materials process review, the design and manufacturing organizations presented process-flow maps in a similarly self-critical manner. This openness allowed for a discussion that was highly educational to all. But more importantly, this resulted in the identification of a large number of process holes.

Recalling the highly competitive nature of the Dell working environment, it is impressive that this group of Executives could put aside their egos, admit their organizations' faults, and propose changes that would improve the performance of the entire company, not just their organization. Through this discussion, it also became painfully clear that all organizations' intense focus on their own metrics had historically led to local optima at the expense of the overall company's performance. Following this productive and collaborative discussion, the Services group agreed to present their process map the following week at the October 15th WWQF.

As a result of these process-mapping discussions, 42 project proposals were developed to address the process gaps and control deficiencies identified. Two examples of the type of projects derived through process-mapping are:

- Implement a standard measurement process for supplier rolling throughput yield.

  Consider again the hypothetical widget supplier described in Chapter 2. If Dell could work with this and other widget suppliers to establish a standard measurement process for rolling throughput yield, it would be possible for Dell to a) determine which suppliers were superior in their manufacturing process, b) calculate the cost reduction opportunity for improvements in supplier rolling throughput yield, and c) assist those suppliers with the largest opportunity to improve their yield, providing savings to both the supplier and to Dell. While this project would primarily be implemented by the Materials organization, it would also require the work of Dell's Design and Manufacturing organizations. The Design organization, which specifies the allowable performance limits of the widget (and even the allowable distribution of performance within those limits), would work with the Materials organization to determine the most cost-effective component specifications that satisfy the product performance requirements. The Manufacturing organization would work with Materials to establish metrology correlations, ensuring that the measurement procedures at the supplier correlate with the measurement procedures in Dell's factories.

- Add new features to the product to allow 'down-the-wire' failure analysis in the field.

  It is possible to design product features that would allow Dell Phone Support technicians to assist a customer with a real or perceived failure by taking control of the customer's computer 'down-the-wire.' Such a feature would allow the technician to quickly run a battery of tests, download software patches real-time, or to activate/inactivate portions of the system to assess the failure and validate the solution. Such 'down-the-wire' features would certainly require significant investment by the Design organization, but would also require support from the Materials and Services organizations. The Materials organization would work

with the suppliers and the Design teams to select cost-effective components for the new circuits. The Services organization would re-train technicians to efficiently use the new diagnostic features and to provide feedback to the Design team on the efficacy of these features.

Both of these examples illustrate the significant investment that may be required by multiple organizations to implement a process-based COQ improvement. To determine which of the 42 COQ proposals should receive Dell's immediate investment, it was necessary to quantify the investment required and the financial benefit expected for each of these 42 proposals.

Prioritizing the proposals

To determine an order-of-magnitude estimate of the investment and expected return for each of the 42 projects, I met with approximately 30 employees across the Services, Design, Manufacturing, and Materials organizations in small group and one-on-one meetings. These estimates were plotted (see Figure 8) to identify those projects with the largest expected ROI. One obvious drawback to this approach is that, like the previous benchmarking effort, it relies again on the subjective opinions of employees who have already exhibited conflicting assumption biases. In voicing this concern, I was reminded that the intent here is to identify actions that are "directionally correct" not the perfect solution set. It is understood that the subjective analysis of expected ROI would include bias. And it is not expected that this prioritization process will precisely yield the top 10 projects. Instead, it is expected that, even with these biases, this prioritization process will yield 10 projects that are among the top 20 or so projects.

Figure 8 is divided into three simple regions. The "Go do it!" region reflects those projects where the expected return is more than ten times larger than the investment. The "Forget it!" region reflects those projects where the expected return is less than one-tenth of the investment. The "Need a business case" region reflects those projects where the expected return is of the same order of magnitude as the investment. In this area, a more detailed argument would be required to justify an investment in the project.

It is worth noting that all of the original 42 projects are expected to improve Dell's product failure rates. If the primary objective of COQ were to simply improve failure rates, the prioritization analysis would have evaluated the expected impact on failure rates, not the expected ROI.

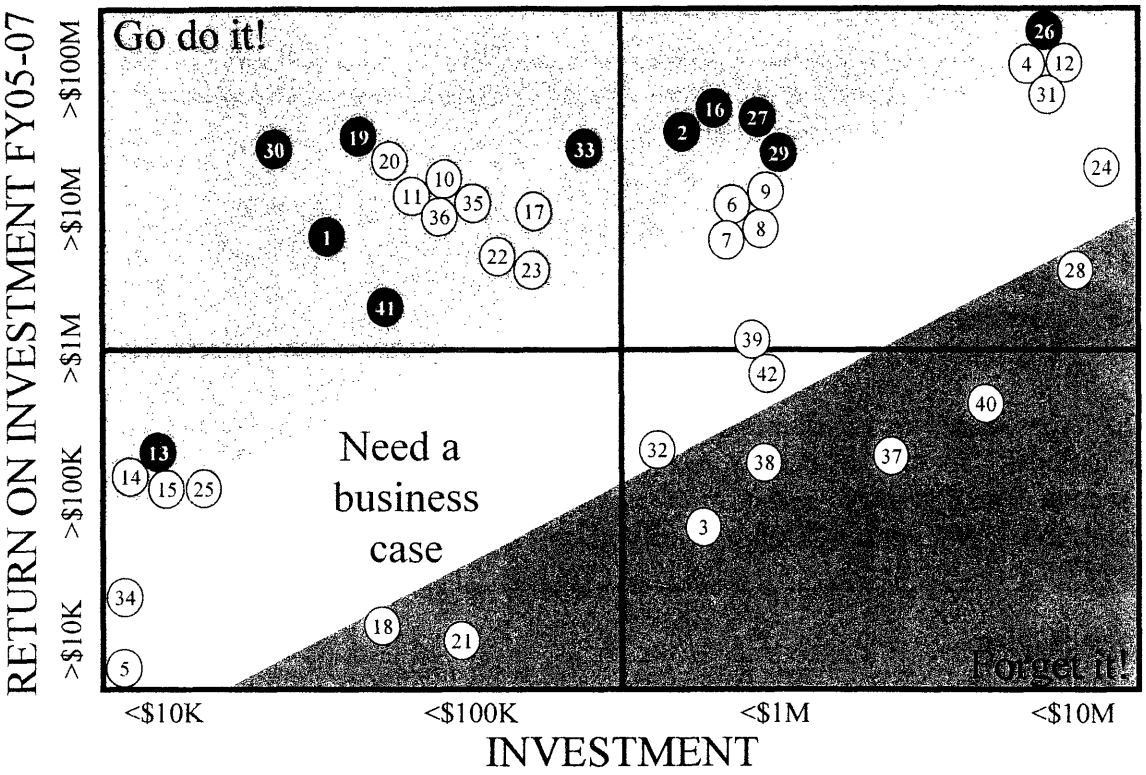


Figure 8 Prioritization process map

Using the input from the small group and one-on-one meetings, Figure 8 was constructed and the 11 highlighted projects (numbers 1, 2, 13, 16, 19, 26, 27, 29, 30, 33, and 41) were selected as promising projects warranting further review. Much of the October 29th WWQF meeting was then dedicated to reviewing this prioritization process and the 11 projects highlighted. After some discussion of resource availability and implementation options, these 11 projects were narrowed to seven projects with clear objectives, clear resources, and a clear path to completion.

CHAPTER 5 – SUSTAINING COQ AT DELL

There are a number of different ways that the Cost Of Quality project can be sustained at Dell. This chapter will detail five different methods that could be used to sustain the COQ initiative. I will term these five methods as:

1. Institutionalization
2. Shadow P&L
3. Organizational Alignment
4. Cross-organizational Metrics
5. Program Management

These five methods are not necessarily mutually exclusive and no one method is appropriate for all situations. It is likely that a combination of some of these methods will be required for Dell to sustain a quality improvement effort such as COQ over the years. It is further likely that the methods that work best for COQ in FY05 will not be the same methods that work best for FY07 or FY15.

Institutionalization

Some companies pursue quality as an end in and of itself. Quality initiatives are pursued for quality's sake, not for any secondary benefits that may arise from that quality initiative. At companies where quality has been institutionalized, quality becomes a trump card, beating out many arguments based on time, money, or technical feasibility. When quality is institutionalized, proposals that are shown to improve quality are approved and proposals shown to have an adverse effect on quality are disapproved; only when a proposal is quality-neutral will other factors be considered. Characterized by "a zero defect" philosophy, the notion is that even a single failure is too many.

The advantage of Institutionalization is that quality is no longer debated. For companies which have tended to relegate quality to an auxiliary role behind factors such as time-to-market, technical performance, or cost, the institutionalization of quality would dramatically alter the decision making process. Instead of quality improvement acting as one of many factors to consider, quality improvement becomes the first consideration.

The disadvantage of Institutionalization is the propensity to go too far. There is a joke in the automotive industry that in a company where "Quality is Job 1" a team of engineers gold-plated a portion of their design. Upon hearing this, the design manager retorted, "We just gold-plated something…I hope it wasn't the shocks." The notion expressed by this joke is that quality for quality's sake tends to forget the needs of the customer. In some cases, exceeding customer expectations may "delight" the customer and engender a customer loyalty that leads to future business. However, it is possible to exceed customer expectations in a way that the customer is either unaware of or ambivalent to. In such a case, the quality-improved design is valueless in the eyes of the customer. Any organization that has institutionalized quality must take steps to align the quality improvement efforts with the customers' wants and needs.

A second disadvantage of Institutionalization is the possibility that such an approach may lead to an excessively large quality organization. At a company where quality is institutionalized, it may become politically incorrect to challenge any quality improvement proposal and those who question the size of the quality organization may be perceived as "uncommitted" to quality improvement. Such an environment may lead to the establishment of a

quality army: quality technicians, quality engineers, quality auditors, quality managers, all of whom are not directly adding value to the product, but instead ensuring that others have added value to the product in a high-quality manner.

For a company that is grossly off-target with respect to quality in an industry where quality is highly valued by the end-user, Institutionalization may be an appropriate method to sustain a quality improvement initiative such as COQ. Creating a culture where quality wins every argument will ensure that decisions are made which improve quality. However, over the years or decades, as quality improves, there may be a point of diminishing return where quality improvement decisions can no longer simply receive a rubber stamp of approval.

For Dell's home consumer markets, Institutionalization appears to be wholly inappropriate. In these markets, the end users do not expect perfection. An occasional re-boot of the system, while not preferred or desired, is certainly not uncommon and will not result in seriously angered customers or in lost business. Even a rare event such as data loss is generally expected, and end users routinely back up their data in anticipation of such an event. That is not to say that Dell should disregard quality improvement initiatives in these markets or that customers are pleased when their consumer product fails. However, it does demonstrate that customer expectations and Dell's quality performance are sufficiently aligned that an Institutionalization approach would be excessive.

However, as Dell moves further and further into high-end Enterprise markets, Dell is encountering customer expectations that are significantly different than those of home consumers. For "mission critical" applications, a day, an hour, or even a single minute of downtime may be unacceptable. For example, the servers, hubs, routers, switches, and storage products that support the New York Stock Exchange, air traffic control centers, or 911 emergency call centers are expected to have virtually no unplanned downtime. Even a single failure at one of these customer's sites could result in millions of dollars worth of damage or even the loss of lives. Computing systems must be designed for these markets such that they have an extremely low incidence of failure and such that the most common failure opportunities have built-in redundancy to minimize the impact to the customer. For other Enterprise customers, downtime may not be as critical as data integrity. For banks and other financial institutions, a single instance of data loss could cost billions of dollars. Again, highly reliable systems must be designed with built-in redundancy to ensure such data loss does not occur.

Such mission critical markets are highly consolidated, raising the stakes for quality even further. A catastrophic failure with a single bank customer may result in not only the loss of that bank's future business, but may result in the loss of future business with most or all other banks in that market segment. To make the Enterprise market even more challenging, server products are far more complex than home consumer products, with 2-5 times the failure opportunities.

In markets such as these, customers are far less price sensitive and are far more focused on product reliability. An Institutionalization approach to quality may make sense for these mission critical markets where quality is highly-valued by the customer and where even a single failure is unacceptable. However, institutionalizing quality for Enterprise products, while maintaining a cost-focused, continuous improvement quality approach for home consumer products, is extremely difficult. Institutionalization is, by definition, a changing of the organizational culture to a quality-above-all-else mindset. Adopting a zero-defect philosophy for Enterprise products is likely to result in new design practices, new procurement practices, and new manufacturing practices. Institutionalizing quality for Enterprise products effectively means that two concurrent organizational cultures must exist side by side, one with quality as the paramount concern and

the other with cost as the primary decision variable. Even top executives may have a difficult time with two concurrent organizational cultures within the same company.

Shadow P&L

Some companies, notably Motorola, have created a behind-the-scenes profit and loss (i.e. a "Shadow P&L") tracking system to specifically account for quality costs (Misczynski). In addition to the financial reporting that is prepared and audited for annual reports and SEC filings, companies may elect to track finances in non-traditional categories for internal-only reports that help to guide day-to-day business decisions. Motorola created an internally-audited system where the costs associated with product inspection, test, scrap, rework, repair, and warranty were tracked on a quarterly and annual basis. This allowed Motorola to consistently track its Cost Of Poor Quality (COPQ) over 12 years and to target the areas within the company that most directly contribute to their COPQ. This also allowed Motorola to ensure that a COPQ savings was not merely the shifting of cost from one accounting center to another.

Without a tightly audited company-wide tracking system such as a Shadow P&L, it is entirely possible for good-intentioned quality projects to simply shift costs around the company. For example, Dell's factories include an organization called Electrical & Mechanical Repair (EMR). During the software download and system test process in the factory (termed "Burn"), it is the responsibility of EMR to remove any product that fails during the system test, to perform a high-level failure analysis, and to repair failed products. As EMR performs a defect management role, the costs of EMR contribute to Dell's COQ. With a heightened focus on COQ, there may be pressure to reduce the cost of EMR. However, if the causes of the failures are not addressed, actions which reduce the cost of EMR may simply result in shifting those costs to other portions of the company. In the worst case, these costs may be shifted downstream to customers, where the costs are magnified (it is far more expensive to repair a failure at a customer's site than to repair that same failure when the product is still within the factory).

The advantages of a Shadow P&L tracking system are its consistency and completeness. As most quality improvement initiatives span multiple years, it is conceivable that the principal personnel involved in the quality improvement initiatives will change over time. Without a Shadow P&L, it is possible that the measurement methods or underlying assumptions for COQ will change as personnel changes. The hard and fast rules associated with an audited tracking system will allow these personnel changes to have minimal impact.

The disadvantages of such a tracking system are its complexity, cost, and perception. Maintaining an entirely separate Shadow P&L is extremely complex and can become confusing as employees attempt to reconcile internal data with the financial data that is published external to the company. And to prepare and monitor a separate set of financial books specific to quality would require additional resources, specifically personnel necessary to perform financial audits and to prepare the financial reports. Even if a company is capable of managing the complexity of multiple financial reporting processes and is willing to carry the cost of such reporting, it is possible that this internal-only financial reporting would become public, with a possible perception of financial manipulation. Investors will need to be reassured that behind-the-scenes financial reports are used to improve the performance of the company and not to hide data. Yet despite the desire to reassure investors, transparency is not necessarily desirable, as it is unlikely that any company would want its detailed costs of quality subjected to public scrutiny.

Cross-organizational Metrics

Most organizations at Dell are primarily focused on improving the metrics for which they are held accountable and are held accountable only for those areas that they can most directly impact. This is perfectly understandable and allows for both a division of tasks as well as clear accountability for those tasks. However, certain initiatives, such as quality improvement, fail to parse into easily-divisible components that can be assigned a single point of accountability.

For example, Dell's Services organization is responsible for engaging with the customer after the customer has purchased a Dell product and experienced a failure, a perceived failure, or has a question about the product. Two metrics that the Services group is held accountable for are Repeat Dispatch Rate (RDR) and On Time First Time Fix (OTFTF). RDR measures how often a part is dispatched to a customer and fails to fix the customer's problem, thereby necessitating another part dispatch to the customer. OTFTF measures the ability of the Services group to address the customer's problem in a timely manner with a solution that works for the customer on the first attempt. In addition to the timeliness consideration, OTFTF may or may not include the dispatch of a part and is therefore a broader metric than RDR. However, both of these metrics address how well the Services group handles an issue after a customer has a real or perceived problem. This may be reasonable, as the Services group does not design, procure, manufacture, or sell the product and therefore does not directly affect the initial quality of the product delivered to the customer.

A principal challenge with quality improvement initiatives is that product quality is not the sole responsibility of any one organization. In fact, it could be argued that all organizations, including Sales, Design, Validation, Procurement, Manufacturing, Test, Services, Human Resources, IT contribute directly or indirectly to the product quality. With so many sources of input for quality performance, there is no one organization capable of being solely accountable.

With this in mind, cross-organizational metrics seek to hold organizations accountable for metrics that are not directly within their control, but to do so in a manner that drives desirable behavior. As an example, holding the Services group accountable for first-time failures would change the way that the Services group interacts with Design, Procurement, and Manufacturing groups. Today, with RDR and OTFTF as metrics, the Services group's activities are focused on initiatives that can improve those metrics. Such initiatives may include improving failure diagnostics, increasing training for customer support technicians, or providing better debugging tools to field service technicians. If instead the Services group were accountable for every failure, first-time or repeat, the problem-solving approach may be quite different. Recognizing that repeat failures account for a small percentage of all warranty costs, the Services group may instead invest in data collection experiments which can guide corrective action in other organizations.

Currently, the Services group does conduct a comprehensive financial analysis of warranty data. This data details precisely where every warranty dollar is spent, by category, by Line Of Business (LOB), by LOB and category, by LOB/category/commodity, etc. Figure 9 is an example of some of the data that this analysis can produce.

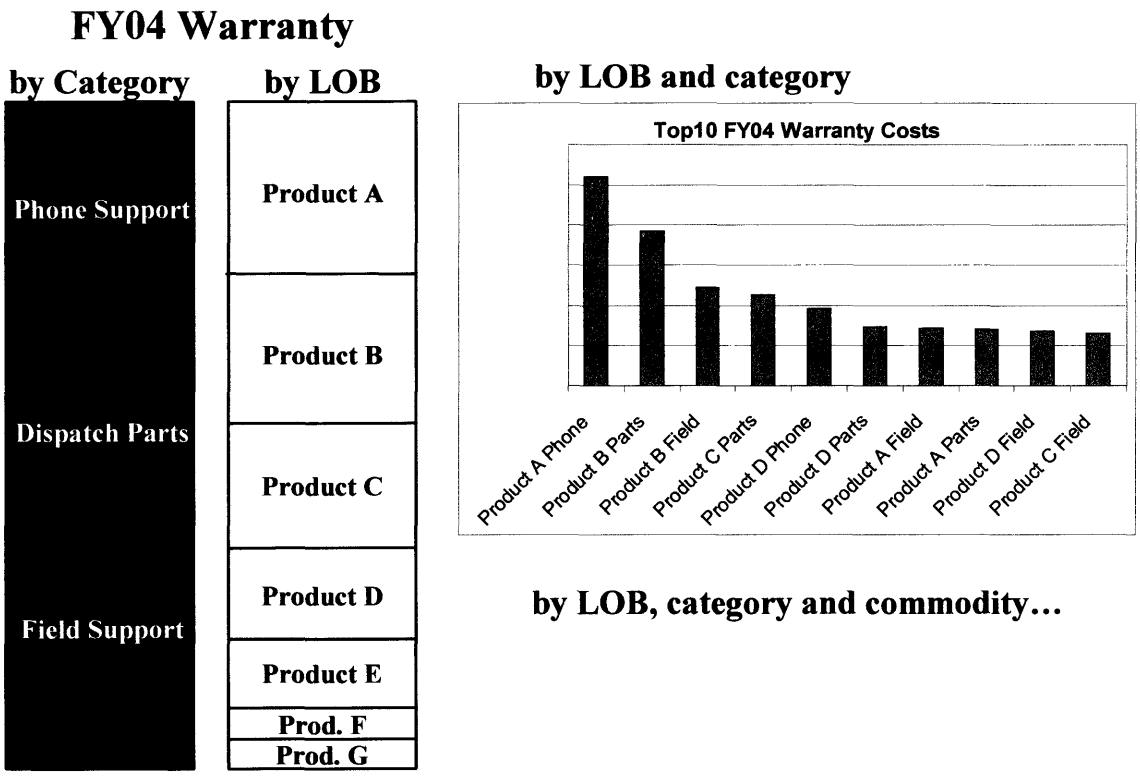


Figure 9 Breakdown of FY04 warranty costs

(actual data removed to protect the confidentiality of Dell financial information)

While this analysis thoroughly details where every warranty dollar is spent, it fails to detail why each dollar is spent. Without understanding the causation behind Product A Phone Support costs, it is not possible to determine which actions will reduce those costs.

As a general rule, the quality issues at Dell and at other companies are a result of an organizational mis-alignment, leading to local optimizations and global sub-optimizations. A system of appropriately crafted cross-organizational metrics is intended to shift the focus away from such localized results.

The advantage of a cross-organizational metrics approach is that it may create incentives for the services organization to work more closely with other groups to determine causation, develop improvement actions, and prioritize those improvement actions based on expected return. Similarly, the design group would be held accountable for Services' performance in providing technical support to the customer. This provides the appropriate incentives for the design group to be diligent in ensuring that the decision trees provided to the services group are complete and accurate.

The obvious disadvantage of such an approach is one of fairness and empowerment. To hold an organization responsible for results that are out of their control (or are perceived to be) will certainly be viewed as unfair and is may result in disregard for the cross-organizational metrics entirely.

Organizational Alignment

In the place of, or in combination with, new cross-organizational metrics which create diverse accountability, it is possible to entirely re-organize a company to create the alignment desired. One possible organizational structure would be market-based, rather than a function-based. In a market-based organization, the functional areas would naturally be more closely integrated, each area possessing smaller scope and greater depth than in a function-based organization. For example, in a function-based organization, the procurement and supplier management function for the entire company is handled by a single organization. This organization is challenged to meet the procurement needs of all the products offered by the company. As the procurement organization is invariably measured by negotiated price reductions, the suppliers' on time delivery, etc., there is a natural tendency for such an organization to focus on the needs of the products with the largest volumes, which will impact the procurement metrics most significantly. Project teams for lower volume products may then struggle to get the support needed to be successful. In contrast, a market-based organizational structure would establish multiple procurement organizations custom-tailored to the needs of that product market. This leads to redundancy of task, as multiple procurement organizations work to manage a similar supply line to procure similar components from similar suppliers.

A market-based organization may become necessary for other reasons, as Dell branches in new product lines with diverse customer needs. As mentioned above, the needs and expectations of the home consumer market are very different than the needs and expectations of the Enterprise market. To understand and satisfy these diverse customer needs, it may be necessary to develop different design rules, materials selection procedures, or manufacturing processes specific for each market segment. It is more likely that a market-based organization would have functional areas more closely linked than would a functional-based organization. But it is also likely that a market-based organization structure would pay for such increased alignment with redundancy and a less efficient workforce.

Another disadvantage of organizational alignment is that such a change is potentially severe and may create fractures that are permanent. After the decision to break into product areas, it is only years later that some companies realize that they have become a collection of unassociated companies under a single financial umbrella. This may be desirable if divesting portions of the business is a possibility some time in the future. However, these disassociations can make it very difficult for functional learnings to be shared across the company.

Program Management

Rather than implementing dramatic changes to the organization, as suggested above, it is possible to simply manage COQ as Dell would manage any other program:

- Define a problem statement
- Define a program objective
- Identify a COQ Program Manager (PM) or manager responsible for a team of PM's
- Provide sufficient authority to the COQ PM's
- Align incentives throughout the company with the COQ objectives
- Develop a process to measure progress toward the COQ objectives
- Measure and track progress
- Recognize and reward the success of the COQ program

Obviously, this is the approach that Dell has been pursuing with regard to COQ to date. With strong support from upper management across many organizations, this has been a

successful method to establish a common understanding of the problem, to arrive at agreement that COQ is a program worth supporting, and to define initial steps to reduce Dell's COQ.

The advantage to a Program Management approach is that a single person, either an individual Program Manager (PM) or a manager responsible for a team of PM's, can be responsible for the success or failure of the COQ initiatives. This accountability can help to ensure that the quality improvement projects that make up Dell's COQ effort are not lost or forgotten between organizations. To be effective, however, this accountability must come with sufficient authority to drive change throughout the company.

Another advantage of this approach is that it is less likely to generate a large number of new quality-specific roles to "over-solve" the problem. Managing COQ as a program ensures that resources are applied to COQ based on expected ROI and puts COQ in a position to compete for resources with every other project or program at Dell. As a cost reduction initiative, it is appropriate that COQ would need to defend its resource usage on an ongoing basis and that this defense would be based on its financial merits. As COQ generates cost savings, organizations throughout Dell will be more willing to invest resources in additional COQ initiatives.

However, there are many disadvantages with a Program Management approach. The most obvious of which is that selecting the right person to lead the COQ program will have a strong bearing on the program's success or failure. The Program Manager responsible for COQ will need to be persuasive across all organizations, effective at demonstrating financial results, and sufficiently technical to communicate effectively with a broad constituency of engineers. This dependence upon the work of a single person is less critical if, instead of a Program Management approach, one of the above organization-wide changes were implemented.

Relying heavily upon the ability of a single person also leaves open the possibility of personnel changes over time. It is inevitable that the Program Manager for COQ will change over time and that some PM's will be more capable and effective than others. In an era of a less effective PM, it is possible or even probable that the entire COQ program will be de-prioritized by organizations across the company. This creates additional work for senior managers and subsequent PM's to resurrect the COQ program at a later time.

Even if the PM is persuasive and effective at demonstrating ROI, there is no assurance that the PM will be able to negotiate real resources from organizations around the company to pursue COQ initiatives. Fundamentally, organizations will allocate resources to attain the business metrics that they are measured against. Surrendering resources for COQ initiatives may be perceived as undermining the organization's "real job" and support for COQ's "side projects" will be minimal and fleeting. It may be possible to create a new incentive metric that would induce organizations to support COQ in the same manner that other programs are supported. But there are other significant disadvantages with the PM approach related to cause and effect which will undermine the ability to establish such a metric. First, even when the COQ program has successfully identified a process improvement with a large and positive ROI, it may be some time after implementation of a solution that the gain is realized and quantified. If the delay between investment and return on that investment is greater than one year, there will be considerable reluctance to support the project. Second, the very nature of the cross-organizational issues identified by COQ suggests that it is likely that the improvements resulting from COQ initiatives will not be realized by the same organization that paid for the resources to implement the solution. It will be difficult to lobby for resources from one organization when the benefits of those resources will primarily improve the metrics of another organization. Third, COQ is a cost reduction program and its efficacy must be measured in dollars. But how does one accurately measure the monetary value of prevention? By their very nature, prevention

benefits are difficult to definitively measure. However, without clear metrics and clear performance to those metrics, any cost reduction savings achieved by COQ may not be perceived as "real savings" to the company.

Sustaining COQ at Dell

Whatever method or methods are employed to sustain the COQ program, three truths will remain.

1) Understanding and meeting the needs of customers is the principal objective for COQ and for any program at Dell. This may entail different quality systems for different customers or market segments. For example, it may be necessary to have different supplier selection and component qualification processes to support the unique needs of the Enterprise and Home Consumer markets.
2) Cost Of Quality for Dell is primarily a cost reduction program and must be managed as such. At Dell, pursuing quality as an intrinsic good fails to comprehend the need to balance customers' expectations for performance, delivery, price, and quality. Even for the Enterprise market, where customers are willing to pay higher prices for lower defect levels, there remains the need to balance the customers' various expectations. While the customers' expectations may vary from market to market, the need to balance those expectations does not change.
3) The support of senior managers across multiple organizations will be critical to the success or failure of COQ. While this may seem obvious and trite, it is clear from the list of the Top 42 COQ projects that the largest opportunities for COQ improvement involve cross-organizational efforts. This implies that organizations' historical focus on internal metrics has led to local optimizations. Without strong senior management support for COQ as a cross-organizational effort, organizations will naturally be inclined to focus on their internal metrics.

CONCLUSION

Dell has the right business model for fast, inexpensive products, and a cost-focused approach that can effectively be used to guide investments in quality improvement. It has been shown that Cost Of Quality (COQ) can be an effective tool to guide failure reduction improvements in a cost-focused organization. With the objective of reducing Operating Expenses while meeting the needs of the customer, COQ faces many organizational and data challenges to be successful. However, much progress has been made.

Under the supervision of Mehran Ravanpay, Dell's Director of Engineering and Quality for Dell Americas Operations (DAO), and with the guidance of Jim Wynalek, Dell's Vice President of Americas Quality, in my 6 months at Dell, I was able to:

1. assess the size of Dell's current COQ and the cost savings opportunity for a reasonable improvement in defect rates
2. describe a vision for process-based quality improvements, distinctly different from current product-based quality improvement efforts
3. persuade a broad constituency of Dell executives of the financial gain that may result from a focused quality improvement effort
4. analyze existing data sources to demonstrate a fundamental gap in the current quality data
5. coordinate the development of a list of tactical projects intended to improve deficient processes which currently lead to quality costs
6. develop a rough return on investment (ROI) analysis to prioritize the tactical opportunities
7. manage the formation of teams focused on each of the tactical opportunities

Some at Dell who previously discounted the value of quality improvement have, in the past six months, become quality advocates, arguing for the need to engender loyalty among customers through improved quality.

As a cost reduction initiative, the Cost Of Quality project has successfully demonstrated significant cost reduction opportunities resulting from improved defect rates. I am pleased to say that Cost Of Quality is now one of Dell's top five projects to reduce OpEx for FY05-FY07.

I would like to conclude this thesis with two recommendations. First, COQ projects now and in the future should be both cross-functional and process-oriented. The opportunities identified to date strongly indicate that improvements in critical inter-organizational processes will significantly contribute to Dell's bottom line. Second, due to the very different expectations of customers in the Enterprise and Home Consumer markets, I recommend that Dell establish distinctly separate design, procurement, and manufacturing methods for these two markets. For example, component specifications, supplier selection processes, and qualification procedures should be tailored to the diverse needs of these two markets.

APPENDIX 1: Selected Dell financial results

In its annual reports, Dell, Inc (formerly Dell Computer Corporation) routinely includes corporate revenue data and profit trends, reflecting the rapid growth of the company[1].

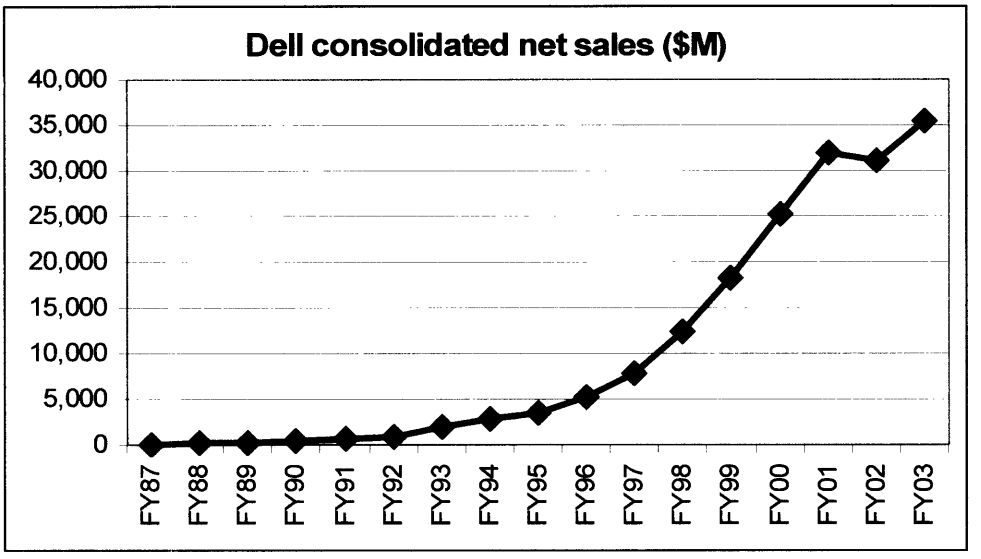


Figure 10 Dell Consolidated Net Sales FY87 – FY03

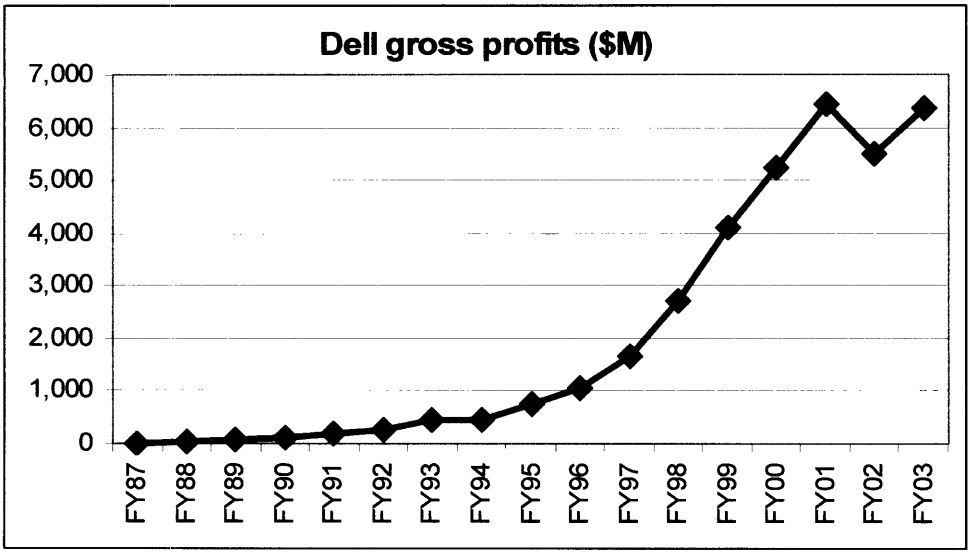


Figure 11 Dell Gross Profits FY87 – FY03

With reported earnings of $41.4B for FY04, Dell is on pace to exceed $60B in consolidated net sales by FY07. During this same period of time, Operating Expenses (OpEx) as a percentage of consolidated net sales has fallen 43.1% (OpEx was 17.4% of net sales in FY87 and reduced to 9.9% of net sales in FY03).

[1] All financial data in Appendix 1 are derived from Dell Annual Reports found at http://www.dell.com/us/en/gen/corporate/investor/investor_annual.htm

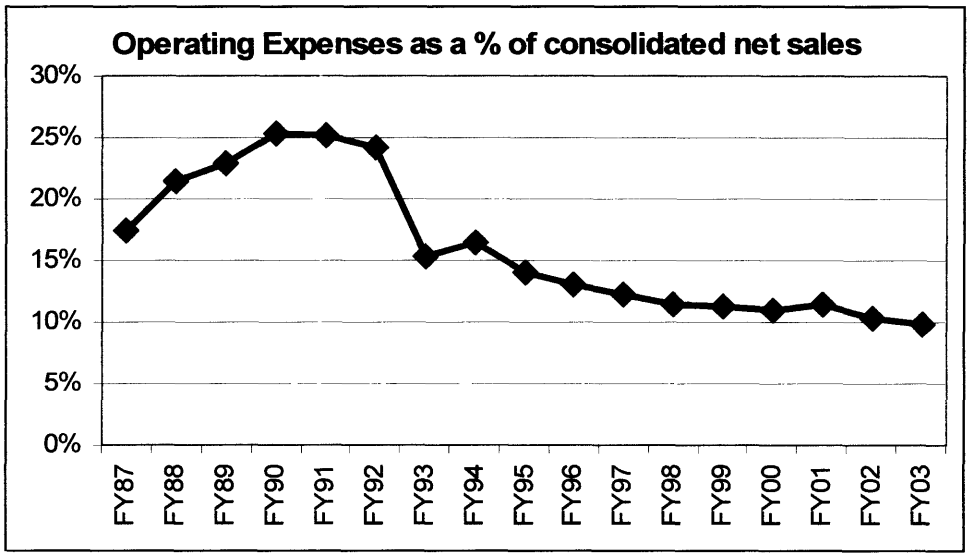


Figure 12 Dell Operating Expenses FY87 – FY03

From FY95 to FY03, consolidated net sales per employee has increased 66.8% (from $543K in FY95 to $905K in FY03).

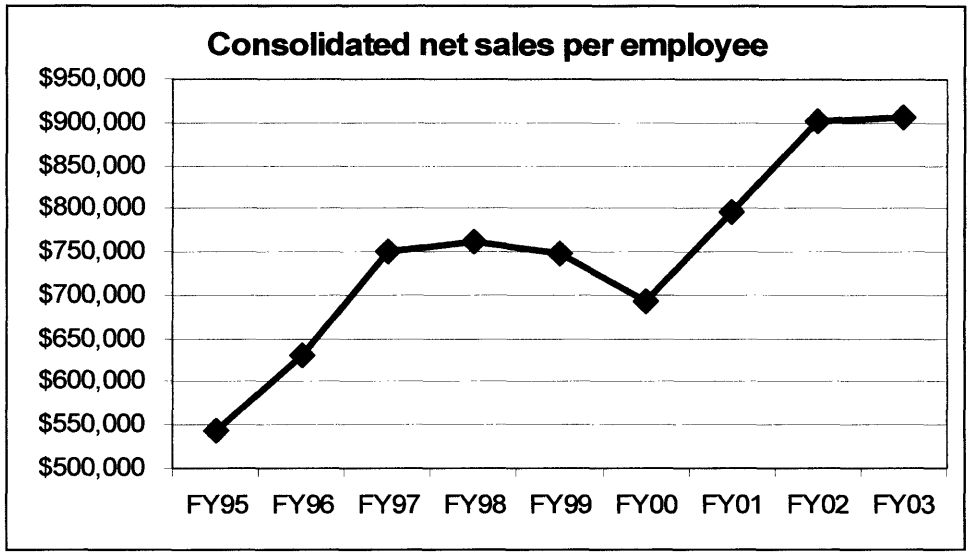
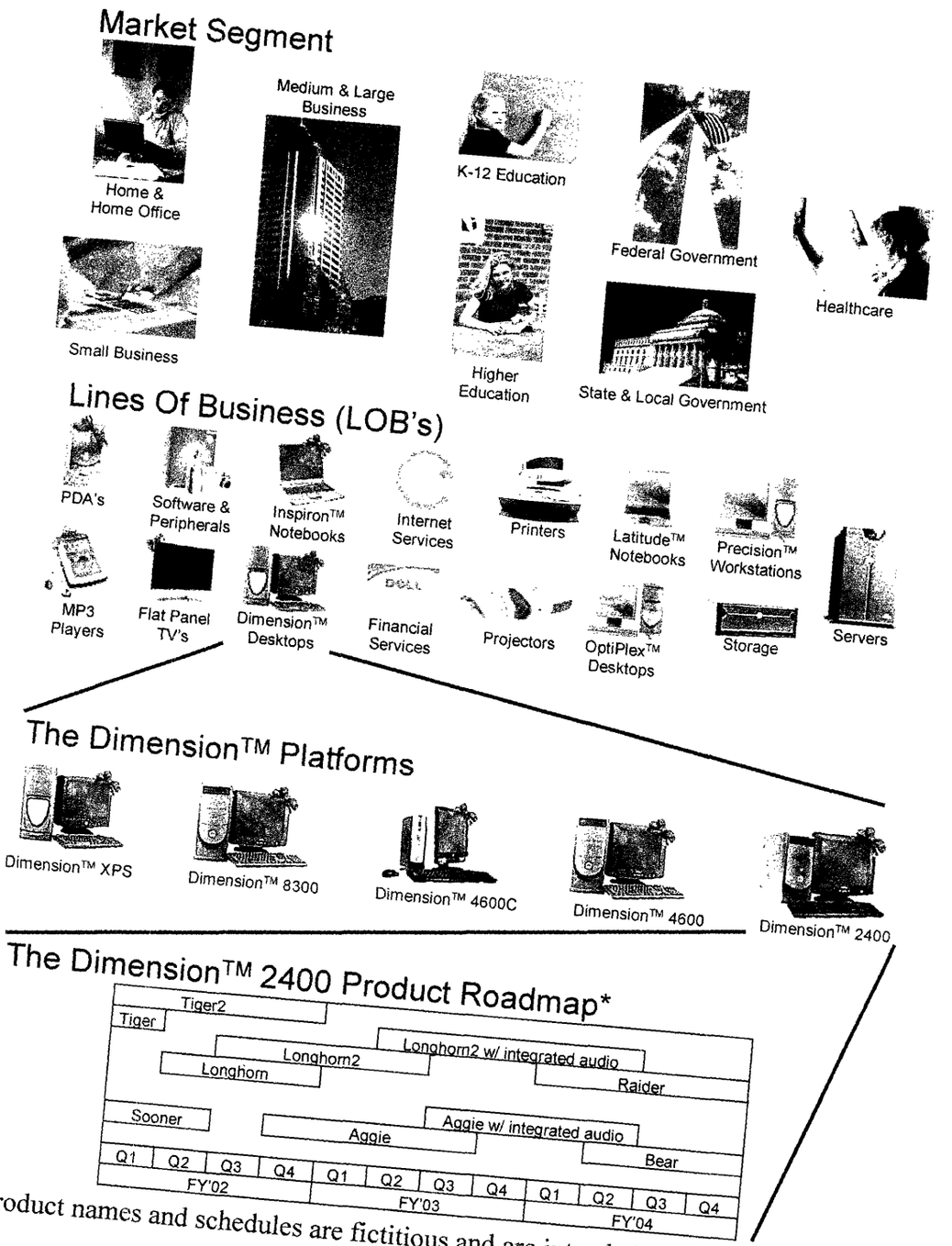


Figure 13 Consolidated Net Sales per Employee FY95 – FY03

APPENDIX 2: Dell's Market Segments, LOB's, Platforms, and Products



*product names and schedules are fictitious and are intended to be illustrative only

Figure 14 Dell's Market Segments, LOB's, Platforms, and Products

APPENDIX 3: Dell's 6σ Business Process Improvement (BPI) Methodology

In the late 1990's Dell's Operations organization defined and implemented a 6 Sigma quality improvement program named Business Process Improvement, or BPI. The name "6σ" refers to the quality level associated with a normal, centered distribution where 99.999998% of the data points lie between the lower and upper control limits. To reflect the reality of normal distributions that are not well-centered between the lower and upper control limits, the 6σ quality level is often calculated with an assumed ±1.5σ mean shift, corresponding to a distribution where 99.99966% of the data points lie between the lower and upper control limits.

Quality level	Percent passing	defects per million (dpm)
±1σ	30.23%	697,700
±2σ	69.13%	308,700
±3σ	93.32%	66,810
±4σ	99.38%	6,210
±5σ	99.98%	233
±6σ	99.99966%	3.4

Figure 15 Relationship between Sigma quality levels and dpm

(Breyfogle, 10)

The quality level of a process can be calculated from a defect per million rate using the following formula:

$$\sigma = 0.8406 + \sqrt{29.37 - 2.221[\ln(dpm)]}$$

Figure 16 Computing Sigma quality levels from dpm

(Breyfogle, 137)

This formula assumes a normal distribution with a distribution center that is ±1.5σ of the midpoint between the lower and upper control limits. Sigma quality levels are often used to communicate pass/fail quality performance, using the above relationship. However, this is not entirely accurate, as pass/fail quality performance fails to exhibit a normal distribution. Despite this misapplication, using Sigma quality levels can be an effective way to communicate quality improvements. The notion of a +1σ quality level improvement was used to define a cost reduction target for the COQ initiative.

Dell's BPI process includes 3 certification levels (Yellow Belt, Green Belt, and Black Belt), organizational goals and metrics related to BPI, and an annual recognition event for top BPI projects. Dell's definition of BPI is:

> "Business Process Improvement (BPI) is a set of tools and applications that drive The Customer Experience. Each of us can use them to understand, ask questions about, and improve processes, thereby adding value to every customer interaction with Dell. It means looking at all aspects of our business – from order-taking

through delivery and post-sale service – from the customer's perspective and asking 'How can we improve our business processes?' "

Yellow Belt training material, page 4

BPI utilizes a 6-step DMAICR (sometimes pronounced "də mā' ĭk plus R") methodology that begins with a traditional 6σ approach (Define, Measure, Analyze, Improve, Control) and concludes with a Report phase that encourages sharing of best know methods that are derived from BPI projects. However, Dell's 6σ approach is decidedly business-oriented. Each BPI project begins with a BPI Project Contract, which includes the project scope, the project objective, the metrics impacted, an improvement goal, an estimated time to completion, and a reason why that particular BPI project was selected considering Dell's limited human resources. The BPI project must be approved by the sponsoring manager, the BPI Area Champion, and possibly others depending upon the organization. In keeping with Dell's culture of staying fast and flexible, some organizations have elected not to utilize the formal BPI Project Contract, but have a management approval process that includes similar content. And in keeping with Dell's focus on financial execution, no BPI project is approved without a Business Case Analysis showing a positive return on investment.

Once a BPI project has been approved, it is entered into an online tracking system that assigns the project a unique BPI Project Number. This tracking system is used to monitor progress for the open BPI projects, to monitor the aggregated BPI savings for an organization, and to track employees' participation in BPI projects. Goals are put in place for the number of employees "engaged" in BPI and for the number of employees that are certified with one of the three BPI Belts. But the most important goal for BPI is each organization's BPI savings target. The BPI savings value determines if a project is a yellow-, green- or black-belt project and it is only through completion of a sufficient number of BPI projects may an employee be certified as a Yellow, Green or Black Belt. In recent years, Dell has successfully closed BPI projects with hundreds of millions of dollars in savings. These savings are internally audited by Dell Financial Analysts and categorized as "hard" savings, "soft" savings, or "avoidance."

The designations of "hard" savings, "soft" savings, and "avoidance" reflect the degree to which a savings activity directly contributes to Dell's immediate Balance Sheet performance.

"Hard savings" are often perceived as the most desirable as these are:

1. a reduction in the current cost structure
2. directly affect profits as reflected in Dell's Balance Sheet
3. measurable against actual results

Examples of hard savings include reductions in headcount, freight rates, scrap, rework, tax savings, prototype costs, or subcontracted services.

"Soft savings" are reductions in:

1. the cost of capital
2. opportunity costs
3. costs not specifically reflected in Dell's Balance Sheet

Examples of soft savings include reductions in inventory or increases in revenue resulting from a warranty upsell or shifting customers from direct technical support to online support.

As the name infers, "Avoidance savings" are actions which delay, defer, or otherwise avoid expenditures that would have occurred without the action. Broadly speaking, avoidance savings result from actions that:

1. increase employee productivity, thereby avoiding the need to hire additional employees
2. reduce space required for an operation, thereby delaying or avoiding the future need to build new facilities
3. reduce customer calls from the field, thereby avoiding the need to hire additional technical support and customer support employees

Avoidance savings is an attempt to encourage appropriate behavior with respect to productivity and efficient use of space, even though the benefits from that behavior are difficult to quantify in the current quarter's Balance Sheet.

The difference between these savings categories can be unclear at times and may depend upon the "baseline" assumption for the business. For example, consider a Dell organization that is expected to increase sales volume and revenue by 10% in the next year. With the same level of defects in the field, it would be expected that there would also be a 10% increase in the number of technical support and customer support personnel necessary to support this increase in sales. If, through lower defect designs or an improved website to resolve customer issues without a call to Dell, the number of calls from the field could be reduced by 10%, then no additional hiring would be required. In this example, the actions that reduced the calls from the field by 10% would be "Avoidance savings" actions.

Consider instead a Dell organization that is not expected to grow sales volume or revenue at all in the next year. Then, the same actions as above would reduce the required technical and customer support headcount by 10%. As this would have a direct effect on the current year Balance Sheet, these actions would result in a "Hard savings." As many managers perceive hard savings as the most legitimate of the three savings categories, the categorization of an action's savings is relevant. A Financial Analyst is usually required to assist in determining the appropriate savings categorization for a given action.

BPI's DMAICR process is valued not only for its results, but for the problem-solving process that it encourages. The Define/Measure/Analyze phases of BPI are intended to be used to tackle ambiguous problems where solutions are unclear, using the statistics-based analysis of data to determine the appropriate solution. Projects where the solution is known in advance are not approved by the BPI Area Champion. The true value in the BPI process is demonstrated when an employee starts with a solution in mind and the DMAICR analysis yields a better solution than the employee was thinking of. However, the pressure for organizations to meet their BPI savings numbers is strong; some organizations will take finished (non-BPI) projects which saved money for Dell and attempt to retroactively apply the BPI methodology, so that the project can be included in the organization's BPI savings. This "slapping BPI paint on a finished project" fails to allow data collection and analysis drive a solution, which is the primary purpose of BPI.

However, there are significant cultural challenges in implementing a process improvement methodology such as BPI in a results-oriented culture. Each year, an increased goal is established for the subsequent year's BPI savings. To meet these aggressive savings goals, managers are tempted to emphasize the result and not the process in their communication to the organization. When a manager communicates the BPI savings goal to their organization and drives their employees to that goal, the BPI methodology can be perceived by employees as not an improvement methodology to make tasks more efficient, but instead just one of many tasks to fill an already busy calendar. As a result, some employees resent the perceived requirement that they participate in a BPI team. "Today, BPI is just another 'rock' for our team members to add

to their already full 'wagon'...Our vision is that BPI be viewed as the 'wagon' used to support each of our business solution 'rocks'." (DAO BPI FY04 Plan)

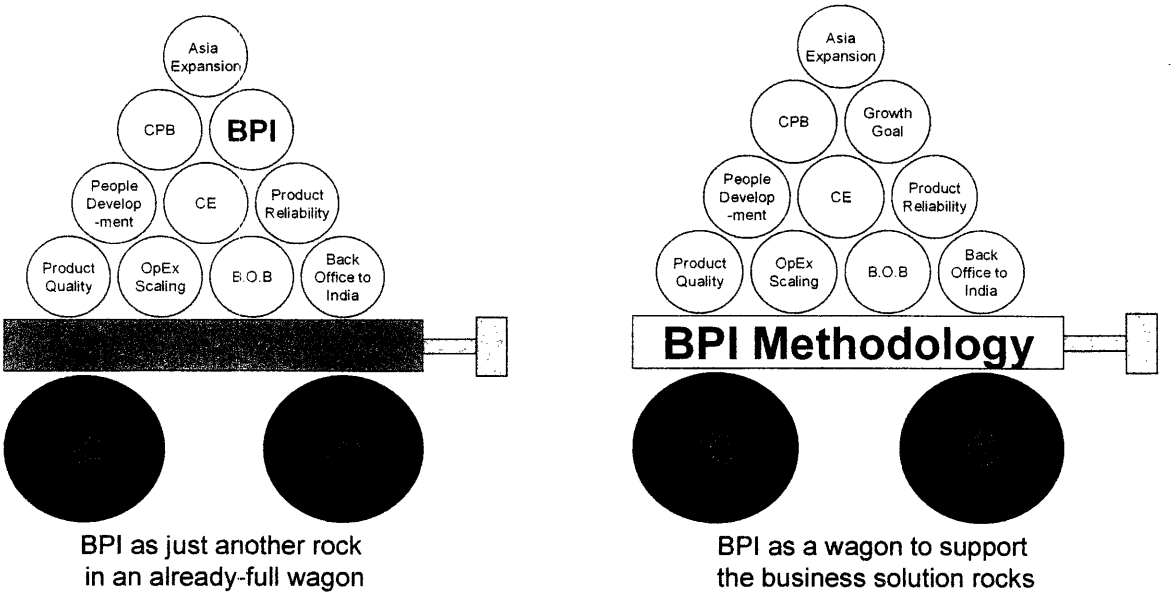
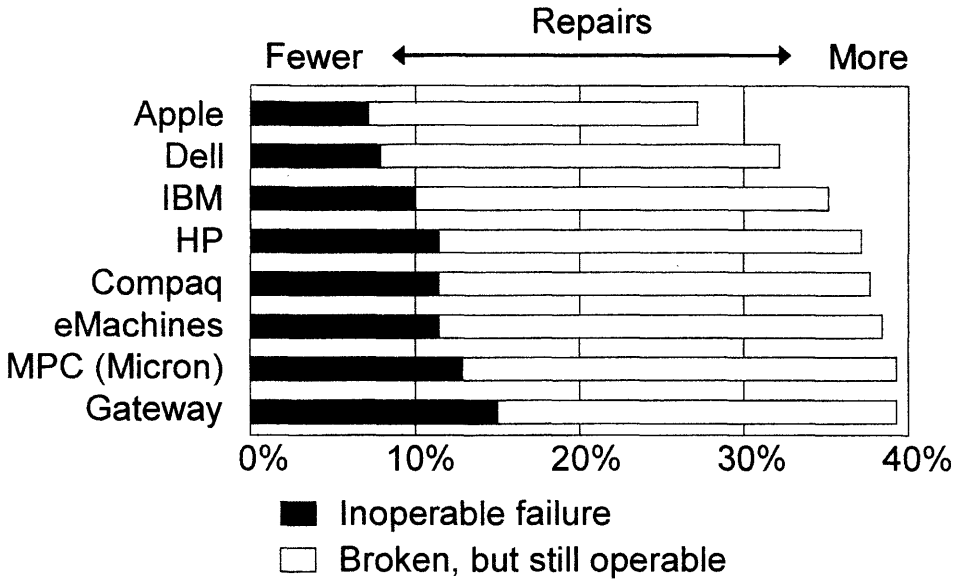


Figure 17 BPI as a methodology to support business solutions

(DAO BPI FY04 Plan)

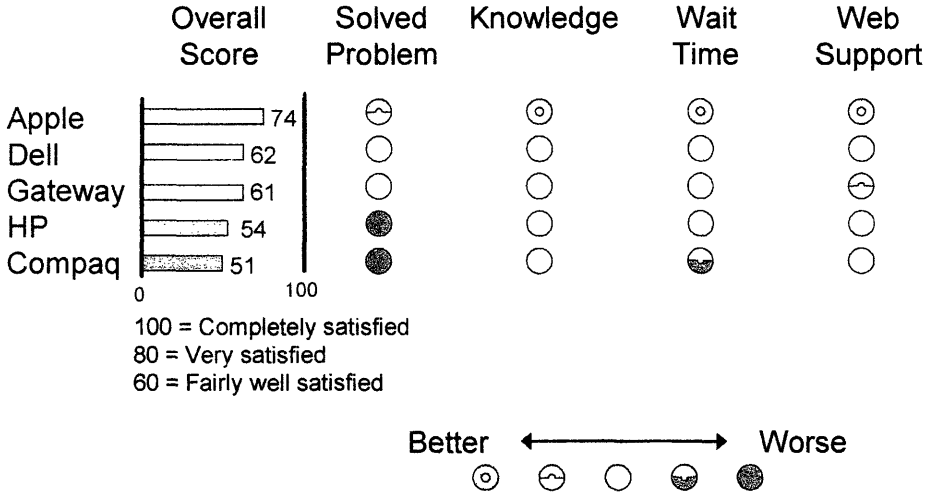
Where executives describe BPI as an empowerment tool for the factory line workers, some workers instead perceive it as a mandate to do more work in addition to their primary function. This is believed to be a result of continuously increasing BPI engagement targets and savings goals. In this way, a strong focus on the results of BPI can undermine the process of BPI. The cultural challenge for Dell's BPI process to be successful is to shift focus away from the financial results of BPI and towards the problem-solving methodology of BPI, which has been shown to deliver amazing results. This will allow BPI to be an empowerment tool that employees can use to make their business processes more efficient, as it was originally intended.

APPENDIX 4: Selected customer satisfaction data for personal computers



("Desktop Computers", Consumer Reports, December 2003)
Based on >54,000 respondents with computers purchased 1999-2003
Differences of 5 or more percentage points are meaningful

Figure 18 Percentage of personal computers requiring repair



("Desktop Computers", Consumer Reports, December 2003)
Based on >4,100 respondents with computers purchased 1999-2003
Differences of 4 or more percentage points are meaningful

Figure 19 Satisfaction with Technical support

APPENDIX 5: Selected price data for personal computers

	Compaq	Dell	H-P	Gateway	Apple	IBM	Sony
Model	Presario 2500	Inspiron 5100	Pavilion ze5700	M350X	iBook	G40	PCG-GRT250
Microprocessor	P4 2 8GHz	P4 2 8GHz	P4 2.8GHz	P4 2 8GHz	G4 933MHz	P4 2 6GHz	P4 2.8GHz
OS	XP Home	XP Home	XP Home	XP Home	Mac OS	XP Professional	XP Home
Software	MS Office SBE	MS Office SBE	MS Office SBE	MS Office Pro	Office v.X for Mac	MS Office Pro	MS Office SBE
Monitor	15 inch SXGA+	15 inch XGA	15 inch SXGA+	15 inch TFT SXGA+	14.1 inch TFT XGA	15 inch TFT	15 inch XGA
RAM	512MB DDR	512MB DIMM226	512MB DDR	512MB DDR	384MB DDR226	256MB DDR266	512MB DDR
Optical drives	DVD/CDRW	24x CD-RW/DVD	DVD/CDRW	DVD-R/-RW/CD-RW	DVD-ROM CD-RW	CD-RW/DVD-ROM	CD-RW/DVD-ROM
Hard drive	60GB 4200rpm	60GB Ultra ATA	60GB 4200rpm	60GB Ultra ATA	60GB Ultra ATA	40GB	60GB
Floppy drive	No	No	No	No	No	3 5" 1.44MB	No
Video card	ATi Radeon	ATi Radeon 7500	ATi Radeon	Intel Graphics	ATi Radeon 9200	ATi Radeon 7500	NVIDIA GeForce4
Audio software	MusicMatch 7.0	RecordNow!Deluxe	MusicMatch 7.0	MusicMaker Deluxe	Garage Band	No	VAIO Creation Suite
Wireless	802.11b/g	802.11b/g TrueMobile	802.11b/g	802.11g	802.11g Airport Extreme	IBM 11a/b WiFi	802 11g
Mouse	USB optical mouse	2-button optical USB	USB optical mouse	EZ Pad pointing device	Apple mouse	IBM USB Optical	Pocketmouse
Keyboard	hp illuminated PS/2	Perf USB Keyboard	hp illuminated PS/2	Full-size keyboard	Apple keyboard	IBM USB Numeric	VAIO USB keyboard
Warranty	1 year limited	1 year limited	1 year limited	1 year limited	1 year limited	1 year limited	1 year limited
Price	$ 1,710.98	$ 1,689.00	$ 1,816.98	$ 1,929 98	$ 1,945.95	$ 1,952.00	$ 2,032 97
Mail-in Rebate	$ 100.00	$ -	$ 100.00	$ -	$ -	$ -	$ -
Price after Rebate	**$ 1,610.98**	**$ 1,689.00**	**$ 1,716.98**	**$ 1,929.98**	**$ 1,945.95**	**$ 1,952.00**	**$ 2,032.97**

3/10/04 data from the www.hp.com, www.dell.com, www.gateway.com, www.ibm.com, www.sony.com, and www.apple.com websites, as a Home or Home Office buyer

Figure 20 Mid-range laptop computers for the home office customer

	Compaq	H-P	Gateway	Dell	Apple	IBM	Sony
Model	Presario S6010V	Pavilion a400y	310S	Dimension 2400	eMac	A30	PCV-RS500C
Microprocessor	Celeron 2.8GHz	Celeron 2.8GHz	Celeron 2.8GHz	Celeron 2.7GHz	Power PC G4 1GHz	P4 2.8GHz	Celeron 2.8GHz
OS	XP Home	XP Home	XP Home	XP Home	Mac OS	XP Pro	XP Home
Software	MS Works	MS Works	MS Works	WordPerfect	AppleWorks	MS Word	MS Works
Monitor	17 inch CRT	17 inch CRT	17 inch CRT	17 inch CRT	17 inch flat panel CRT	15 inch CRT	15 inch flat panel LCD
RAM	256MB	256MB	256MB DDR	256MB DDR	256MB SRAM	256MB	256MB DDR
Optical drive #1	DVD-ROM	DVD-ROM	CD-RW/DVD	CD-RW/DVD-ROM	CD-RW/DVD-ROM	CD-ROM	DVD-ROM
Optical drive #2	CD-Writer	CD-Writer	No	No	No	CD-RW	CD-RW
Hard drive	40GB Ultra DMA	40GB Ultra DMA	40GB Ultra ATA100	40GB Ultra ATA100	40GB Ultra ATA	40GB	80GB
Floppy drive	No	No	No	No	No	3.5" 1.44MB	3.5" 1.44MB
Video card	Intel Graphics	Intel Graphics	Intel Graphics	Intel Graphics	Integrated	Intel Graphics	ATi Radeon 9200
Mouse	Optical mouse	HP Scroller mouse	Logitech PS/2	Dell 2-button USB	Apple mouse	IBM USB Optical	PS/2 Mouse
Keyboard	Compaq Keyboard	HP internet keyboard	104+	Dell Quiet Keyboard	Apple keyboard	IBM Preferred Pro	VAIO Keyboard
Warranty	1 year limited	1 year limited	1 year limited	1 year limited	1 year limited	1 year limited	1 year limited
Price	$ 677 00	$ 684 98	$ 659.98	$ 718.00	$ 947.00	$ 997 99	$ 1,288.48
Mail-in Rebate	$ 150.00	$ 100.00	$ -	$ 50.00	$ -	$ -	$ -
Price after Rebate	**$ 527.00**	**$ 584.98**	**$ 659.98**	**$ 668.00**	**$ 947.00**	**$ 997.99**	**$ 1,288.48**

3/11/04 data from the www.hp.com, www.dell.com, www.gateway.com, www.ibm.com, www.sony.com, and www.apple.com websites, as a Home or Home Office buyer

Figure 21 Entry-level desktop computers for the home customer

APPENDIX 6: Process failure modes

DESIGN	
DFX gap -	The product design failed to consider the manufacturability, test, or serviceability requirements of the product
Stack-up tolerance -	The worst-case specifications of two (or more) parts mechanically interfere
Component selection -	The design included a defect-prone component
VALIDATION	
FW/BIOS validation -	The product included a Firmware or BIOS defect that was present in the design at RTS
Electrical validation -	The product included an electrical defect that was present in the design at RTS
Product validation -	The product included a mechanical or interaction defect that was present in the design at RTS (incl. all shock/vibe failures)
Software validation -	The product included a defect in its drivers or other software that was present in the design at RTS
Regression validation -	The product validation failed to evaluate down-rev software or hardware
CHANGE	
ECO -	An Engineering Change Order was mis-managed
Supplier capability/control -	A supplier's process was either not sufficiently controlled (i.e. Cp/Cpk < 1.0) or a supplier's process capability was insufficient to meet the specified requirements
New component introduction -	A failure resulted from a new component introduction
MATERIALS	
Component qualification -	The qualification process for component was insufficient
Not all suppliers tested -	One or more suppliers were not physically tested
Poor/missing spec -	The specification is insufficient
MISCOMMUNICATION	
Communication gap -	Expectations/deliverables were not clear between two internal Dell organizations or between Dell and a supplier
Usability gap -	The customer used the product in an unexpected way, leading to a failure
OTHER	
Manufacturing process -	The manufacturing process at Dell induced the defect
No process exists -	No process exists
Acoustics -	All noise-related failures
Reliability -	The product had a wear-out or fatigue prior to warranty expiration
Project Management -	A failure in managing the project led to defects
Cost tradeoff -	A cost/quality analysis was performed and the lower cost/lower quality design solution was selected

APPENDIX 7: Definitions and Acronyms

σ – Sigma = $\sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}}$ where x_i is the data values, $\bar{x}$ is the average of all the x_i data, and n is the size of the sample data

6σ – 6Sigma, a quality level associated with a normal, centered distribution where 99.999998% of the data points lie between the lower and upper control limits; to reflect the reality of normal distributions that are not well-centered between the lower and upper control limits, the 6σ quality level is often calculated with an assumed $\pm 1.5\sigma$ mean shift, corresponding to a distribution where 99.99966% of the data points lie between the lower and upper control limits; a 6σ quality level corresponds to 3.4dpm (Breyfogle, 10)

ARC – Americas Remanufacturing Center

AOQL – Average Outgoing Quality Limit

BIOS – Basic Input/Output System

BPI – Business Process Improvement (see Appendix 3)

CCC – Cash Conversion Cycle; a positive Cash Conversion Cyclce is one in which cash is collected from customers prior to paying for operating costs

COPQ – Cost Of Poor Quality

COQ – Cost Of Quality

DAO – Dell Americas Operations

DFX – Design for "X", where "X" may be Manufacturing (DFM), Test (DFT), Serviceability (DFS)

DOE – Design Of Experiment

dpm – defects per million

DPMO – defects per million opportunities

DSP – Dell Service Provider; DSP's are 3rd party contractors that service Dell products in the field on Dell's behalf

EMR – Electrical & Mechanical Repair

FA – Failure Analysis

FMEA – a Failure Mode and Effect Analysis is a method for anticipating design or process failures; FMEA is generally a three-step process: 1) identify all possible failure modes for a product or process, 2) identify the effect of those failure modes, and 3) estimate the probability of occurrence for each failure mode and the probable cost of each failure mode (Pyzdek, 151)

FPY – First Pass Yield; for serial operations, the First Pass Yield is a product of the percentage of parts that pass through Operation 1 without failure times the percentage of parts that pass through Operation 2 without failure times the percentage of parts that pass through Operation 3 without failure, etc.

FY – Fiscal Year; Dell's Fiscal Year ends on January 31 (i.e. FY04 is Feb. 1, 2003- Jan. 31, 2004)

HDD – Hard Disk Drive

IT – Information Technology; also refers to the organization within a company that manages the Information Technology assets for the company

LOB – Line Of Business, such as Dimension, Inspiron, Latitude, OptiPlex, etc; see Appendix 2 for an example of the relationship between Market Segments, LOB's, Platforms, and Products

MIL-STD – a variety of specified Military Standards
MTBF – Mean Time Between Failures
OOC – Out Of Control condition
OpEx – Operating Expenses
OS – Operating System
OTFTF – On Time First Time Fix
PC – Personal Computer
PCBA – Printed Circuit Board Assembly
PG – Product Groups, the Design organizations at Dell
QA – Quality Assurance
QC – Quality Control
QFD – Quality Function Deployment; the means by which customers' needs are translated into technical requirements, often documented with a House Of Quality table
RDR – Repeat Dispatch Rate
ROI – Return On Investment
RTS – Release To Ship
SEC – Securities Exchange Commission
SOR – Statement of Requirements
SPC – Statistical Process Control
TQM – Total Quality Management
TS – Tech Support
WWP – World Wide Procurement
WWQF – World Wide Quality Forum; an Executive-level meeting with Director and VP's from Materials, Services, Manufacturing, and Design intended to address cross-organizational quality issues

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