ERGONOMIC PRODUCT AND PROCESS DESIGN

by

Sara Beth Mortenson Schiveley
B.S., Chemical Engineering
Rensselaer Polytechnic Institute, 1997

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

Master of Business Administration
and
Master of Science in Materials Science and Engineering

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ABSTRACT

Ergonomic injuries are not the result of acute events. An ergonomic injury develops gradually from continued actions combining force, motion repetition, posture, and duration. Because these injuries accrue over time, it is often difficult to determine their causes. Lacking a clear causal link, it is difficult to justify investments that are intended to prevent ergonomic injuries.

A large computer manufacturer, Dell Inc, is targeting significant reductions in their factory injury rates. This thesis describes the evaluation of two desktop computer manufacturing facilities. As part of this work, OSHA logs from 2002 were analyzed, injury costs were collected, factory workers were surveyed, and biomaterials associated with ergonomic injuries were studied. The analysis of the OSHA logs determined that 70% of factory injuries were ergonomic in nature and that a majority of the ergonomic injuries occurred as a result of work in the computer assembly (build) area. The costs associated with ergonomic injuries were computed on a cost per box (CPB) basis, a common metric used throughout Dell factories to determine financial impact.

In order to evaluate, improve, and monitor the ergonomic factors on the factory floor, an evaluation tool for product and process design was developed. This tool incorporates risk factors of force, motion repetition, and posture while determining ergonomic scores for products and process steps. Tool validation was achieved by comparing ergonomic scores with worker product preferences, as revealed by an employee survey. Currently, the ergonomic evaluation tool is being used by the Environmental, Health, and Safety (EHS) Department at Dell.

A greater understanding of the causes behind ergonomic injuries, combined with use of the evaluation tool, is contributing to Dell's efforts to continuously reduce the occurrence of ergonomic injuries and associated costs.

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In addition, I would like to recognize my thesis advisors, Roy Welsch and Jack Dennerlein, and my thesis reader, Tom Eagar. You provided critical support and guidance. I appreciate your willingness to contribute to this project.

This work was initiated by the Environmental, Health and Safety (EHS) Department at Dell, Inc. Thank you for allowing me to collaborate with you. I hope the work done on this project will continue to provide benefit to Dell and its employees. Specifically, I wish to thank my supervisor, Kathy Plattor, and the director of EHS, Jannie Lathan.

Throughout the past two years, I have developed many new friends amongst the LFM Class of 2004. Getting to know you, sharing fun times, and learning from one another has been excellent. I will forever cherish our memories and I look forward to remaining close friends.

Finally, I wish to thank my family. To my parents: Thank you for supporting me, encouraging me, and always believing in me. To my husband, Steve: Our time at MIT has been an incredible journey. Thank you for your friendship, support, and love.

INTRODUCTION

Dell is working to reduce the number of injuries occurring on its manufacturing floors, improve the safety of its employees, and reduce costs associated with injuries. Due to the high level of repetitive work when building computers, a large percentage of Dell's injuries are ergonomic in nature. Many factors impact an employee's propensity to develop an ergonomic injury. Some of these factors include forces exerted by the employees, repetitive movement of their joints, and the posture in which they perform their work. The computer design and configuration, workstation layout, factory process flow and policies, and employee incentives and metrics influence these ergonomic factors. Product assembly, product design, process engineering, and Environmental, Health, & Safety (EHS) are the main groups that impact the ergonomic risks on the factory floor. In order to reduce ergonomic injuries, collaboration and commitment to employee safety are necessary from all of these organizations.

Traditionally safety at Dell has been addressed as issues or injuries occurred. Dell identified the need to expand its focus from a predominantly reactive approach to a more proactive approach. Finding injury trends was difficult and there wasn't a database to historically view ergonomic injuries by area in the factory, type, cause, or severity. In addition, ergonomics in the factory wasn't often made a priority in the design of new computers or factory processes.

In 2003, EHS was given a new focus and headcount was added. The expanded group had a goal to reduce employee injuries by 30% in its first year. The organization was successful in its first year and is targeting an additional 40% reduction in 2004. In order to engage the organizations influencing ergonomics, this ergonomic product and process design project was initiated. Goals for this project included analyzing the ergonomic situation at two selected Dell factories, defining the cost of factory ergonomic injuries, identifying the greatest opportunities for improvement in reducing the occurrence of ergonomic injuries, and developing tools for product design engineers and factory process engineers to evaluate ergonomic risks on the factory floor.

The following thesis will describe this project in detail. Below is a summary of the chapters to follow:

CHAPTER 1: ERGONOMICS provides an introduction to the field of ergonomics, ergonomic statistics, and injury prevention techniques.

CHAPTER 2: THE DELL ENVIRONMENT discusses the business strategy, organizational structure, and culture of Dell.

CHAPTER 3: PROJECT STRATEGY provides an overview of the general project strategy and discusses the tactical approach to this project.

CHAPTER 4: ANALYSIS presents the results of the analysis portion of the project. Results and conclusions of studies performing an ergonomic injury analysis at two factories, an analysis exploring the cost of ergonomic injuries, a discussion the tissue damage resulting from Dell's most frequent injuries, a factory ergonomic assessment, and a build associate survey are presented.

CHAPTER 5: ERGONOMIC DESIGN GUIDELINES AND SCORECARDS discusses the development of the design tools, the procedures for use, the limitations and validations of the scorecards, and steps for implementation.

CHAPTER 6: RECOMMENDATIONS presents the overall recommendations that were developed as a result of this project aimed at improving the ergonomics and safety of Dell's employees while generating cost savings for Dell.

CHAPTER 1: ERGONOMICS

In order to better understand the challenges of this project, it is critical to understand the field of ergonomics. This chapter will provide an overview of ergonomics, discuss the history of ergonomics and the status of the field today, and present two methods of injury prevention.

What is Ergonomics?

Common phrases describing the field of ergonomics include:

- Fit the task to the person
- Work smarter, not harder
- User-friendly

(MacLeod, 5-6)

Ergonomics is a comprehensive subject that addresses work issues on the job, at home and even during leisure activities (MacLeod, 6). A schematic describing the scope of ergonomics can be found in Appendix 1.

Ergonomics can be defined as the science of matching work demands to that of human capabilities (OSHA Website). When the work demands exceed human capabilities, ergonomic injuries can develop. The most common class of ergonomic injuries is musculoskeletal disorders (MSDs). Cummulative Trauma Disorders (CTDs) and Repetitive Strain Injuries (RSIs) are synonyms for MSDs (MacLeod, 9). MSDs include gradual or chronic development of disorders of the muscles, nerves, tendons, ligaments, joints or spinal disks (OSHA Website). Carpal Tunnel Syndrome (CTS) and Epicondylitis (Tennis Elbow) are two commonly known MSDs. It is critical to point out that ergonomic injuries are generally not the result of acute events such as trips, slips, cuts or falls.

There are many risk factors that influence an individual's propensity to develop an ergonomic injury. Some ergonomic risk factors include posture, force, motion repetition, task duration, genetics, and age. Workplace ergonomic risk factors can be direct, indirect or personal in nature. A direct risk factor is one that is developed as a result of the daily job requirements. Examples of direct risk factors include repetitive arm and shoulder motion to open boxes, forces required to insert a component, and bending required to lift a product. Additionally ergonomic risks can be influences by indirect attributes. Examples of indirect risks include the height of a workbench or the reach distance to a tool. The propensity to develop an ergonomic injury can be affected by personal risk factors. Some of these risk factors include off-work activities, physical condition, genetics, and age.

Ergonomic Statistics and Impacts

Though the fundamental ideas of inventing methods and tools to make tasks simpler have been around for thousands of years, a recognizable change in approach occurred in the World War II era. Engineers and scientists were studying human capabilities and limitations in aims to improve the design of military aircraft (MacLeod, 6). It is during this time that ergonomics as described today was established. This new methodology was systematic and analytical.

In the last twenty years, awareness of ergonomics and ergonomic injuries has increased. Extensive physical, psychological, and financial studies have been performed. Collaborations between universities, industry, federal governments and state governments perform and support much of the work involving ergonomics. Some of the topics explored in the field of ergonomics include; human capabilities, anthropometrics, biomechanics, workplace configurations, and product design. Studies looking at human capabilities include exploring a population's strength abilities, understanding humans fatigue levels, and recognizing the impact of posture. Anthropometrics is the study and measurement of the dimensions of the human body and its segment proportions (Kroemer, 4). Anthropometric data for a variety of populations can be found in Appendices 2 - 5. Human body dimensions are critical in the study of ergonomics. Biomechanics explain the body's systems in mechanical terms (Kroemer, 101). Biomechanics involves measuring and modeling the body's mechanical ability to perform work. It allows for the calculations of torques and forces generated by joints and can determine strains on muscles, bones and other tissues (Kroemer, 121). Ergonomic workplace and product design efforts are combining knowledge of human capabilities, anthropometrics, and biomechanics.

The prevalence of ergonomic injuries is significant. MSDs of any cause are one of the most common medical issues. Seven percent of the population has an MSD. In addition, fourteen percent of physician visits and nineteen percent of hospital stays are the result on an MSD (Document #705011). A study of US companies by the Bureau of Labor Statistics (BLS) determined that 62 percent of all workplace illnesses in 1995 were caused by disorders associated with repeated trauma (Document #705011). This statistic did not include back injuries.

Ergonomic injuries come with significant direct and indirect costs. An analysis of workplace ergonomics performed by the State of Washington indicated that its state's total insurance claims associated with work-related MSDs averaged $423 million dollars per year from 1990 to 1998 (Cost-Benefit, 1). This direct cost of insurance claims included losses associated with medical costs and worker's compensation. There are also additional indirect employer costs associated with absenteeism, training due to employee turnover, and lower productivity. Indirect costs that cannot be quantified in terms of financial costs are those endured by the injured employee. The employee can be greatly impacted as the result of an ergonomic injury. Their abilities to perform everyday tasks can be jeopardized. This can negatively affect their ability to perform family and social roles. Ergonomic injuries can cause people to live with continual pain and depression. One employee describes the impact a work-related MSD has had on his life:

> "Right now, when I go home, I have a third grader that's trying to learn cursive writing, and I can't even write a letter of upper case Ds without being in intense pain. I'm not going to have that opportunity to teach my third grader how to write cursive Ds again. I mean, it's like – you don't get to put your life on rerun or on instant replay. You don't get second chances."
>
> (Cost-Benefit, 55)

Due to differences in job nature, task requirements, and company culture, ergonomic risks vary by industry and company. Some of the industries with the highest occurrence of ergonomic issues are the healthcare, services, construction, retail, and manufacturing (USDL, 6).

In the United States, OSHA, the Occupational Safety and Health Administration, plays a crucial role in improving the work conditions for employees. Its mission is to save lives, prevent injuries, and protect the health of America's workers (OSHA Website). OSHA was established as a result of the Occupational Safety and Health Act of 1970 and is a part of the Department of Labor.

There are many ways in which OSHA addresses ergonomics. They have developed a four-pronged approach to safety and ergonomics. The approach includes guidelines, enforcement, outreach and assistance, and a national advisory committee (www.osha.gov/ergonomics). The guideline approach involves developing protective standards for the workplace. In order to provide enforcement, they perform audits and have the ability to distribute fines. In addition, OSHA provides technical assistance to industry and offers consultation programs. They are active participants in many conferences and consortiums. The National Advisory Committee is tasked with identifying gaps in the research on ergonomics. Figure 1 below depicts OSHA's four-pronged approach to ergonomics.

(Adapted from OHSA's Ergonomics Website)

Figure 1: OSHA's Four-Pronged Approach to Ergonomics

Government-funded research in occupational safety and health is primarily carried out by another federal organization, The National Institute for Occupational Safety and Health (NIOSH). NIOSH was also created by the Occupational Safety and Health Act of 1970 and is part of the Department of Health and Human Services. It works collaboratively with OSHA. NIOSH is responsible for conducting research and making recommendations for the prevention of work-related injury and illness (NIOSH Website). In addition, NIOSH performs safety training and education to industry.

NIOSH focuses and supports research on ergonomics. NIOSH shares the results of its ergonomic research. They publish many documents to enable increased awareness and learning on the topic of ergonomics. Through research supported by NIOSH, the NIOSH lifting equations were generated. The lifting equation is a tool to determine human lifting abilities.

Building on the work of OSHA, NIOSH and additional work in ergonomics, the State of Washington developed its own major study and consequent guidelines for ergonomics. In addition to reviewing the ergonomic injury incident rates in Washington, their study included an in-depth cost analysis on the impact of ergonomics. They estimate that compliance with their ergonomic guidelines will cost Washington state businesses a total of $80.4 million annually. In return, the benefit to the businesses and the community will be $340.7 million annually. Their calculations indicate a positive benefit-cost ratio of 4.24 to 1.00 for the implementation of their ergonomic program. This study provides an example of the potential for ergonomic improvements, both financial and societal.

The European community has also been very successful in its efforts to understand ergonomics and generate tools to prevent injuries. The Department of Trade and Industry (DTI) in the United Kingdom has performed a multiphase study collecting human strength data to assist safer designs of products, work areas, and tools.

Injury Prevention

In general, there are two standard methods for improving safety and reducing injuries. The first method is most commonly used. The second method is more difficult to implement, but has a greater potential impact.

The first method is reactive and is initiated by an injury investigation. The method entails the following activities: an injury occurs, an investigation is preformed, a cause is identified, and corrective action is put in place to prevent repeat or similar incidences. This is the simplest injury prevention approach; however it is strictly a reactionary approach. Often times a successful corrective means of action is difficult to identify and implement. Thus, weakening this approach's ability to improve safety and prevent injuries.

The second method is a more proactive and systematic approach to safety. This method involves incorporating safety and injury prevention as part of the organization's culture and decision making processes. Early decisions regarding factory processes, layouts, and product design include a safety evaluation. When embraced and fully implemented, this method is a very successful approach to injury prevention. The project described in this thesis takes this proactive approach to ergonomic improvement and injury reduction in Dell's factories.

A brief introduction into the field of ergonomics demonstrates the impact this issue is generating in industry and society. Many organizations across the world are working to gain a greater understanding of the field and provide tools to prevent further ergonomic injuries. This project will leverage the knowledge of these efforts while generating awareness of ergonomics and its impact in Dell's factories.

CHAPTER 2: THE DELL ENVIRONMENT

As with any project aimed at influencing a cross-functional change in behavior, it is critical to review the company environment. In order for this project to be successful, EHS will continue to encourage other organizations to change their decision making processes and include safety and ergonomic considerations. This chapter will explore Dell's corporate strategy, organizational structure, incentives and culture. Understanding, considering, and incorporating these aspects of Dell' environment in the project strategy are necessary for project success.

Business Strategy

Dell's key business strategy is its direct model. Dell sells computers and computer-related products and services direct to the customer without the use of retailers. This provides many unique benefits for Dell that other computer manufacturers do not share and haven't been able to replicate.

As a result of the direct model, Dell has a positive cash conversion cycle. They don't build a computer until the customer has paid for it. They have direct access to customers and are able to customize a system to an individual's needs. In addition, they can manipulate demand based on supply through real-time price adjustment on their website. Dell also promises quick product delivery, often less than a week from order time to delivery on the customer's doorstep. In many cases, delivery times are measured in mere days.

Because Dell waits to manufacture a product before it is ordered and promises fast delivery, things at Dell move fast. The general fast pace of the electronics and computer industries adds to their need to adapt, change, and operate quickly. The speed at which Dell operates with extremely high productivity levels is referred to as "Dellocity."

Dell also is known to offer low product prices to its customers while maintaining a great profit margin. They are the only computer manufacturer still continuing to manufacture desktop computers in the United States. These three factors; competitive prices, strong profit margins, and US manufacturing, ensure that the focus at Dell is on cost, *low* cost.

Because of the direct model and Dell's continued strive for financial success; Dell operates its business by utilizing a strong metric-based performance system. The metrics each organization is measured on value, and ultimately demand, high productivity and low cost. In addition, Dell has clear metrics for all employees; managers, factory associates and engineers, and for all its suppliers. The pressure to achieve one's goals is extremely high at Dell. As one Austin-based employee described, "No one at Dell misses their metrics."

Organizational Structure and Incentives

Dell's organizational structure is composed of the following major functional business organizations:

- Sales & Marketing
- Product Group
- Operations
- Services
- Finance

These functional organizations are segmented by business units to various degrees. Business unit segments include home & home office, small business, medium & large business, government, education, and healthcare.

Dell's business strategy clearly defines incentives for each of these organizations. Most often these deliverables are focused on cost and productivity. The ergonomics project at hand focuses on considering ergonomics in the design of new products and process equipment. The Product Group at Dell is responsible for the product development process. They design new systems, select supplier components, and develop test methods. The Operations group is responsible for converting raw materials to finished goods. This responsibility involves all activities in the factory from factory layout and design, equipment design, selection, and operation, and product assembly and shipping. The Product Group and Operations are the two main organizations involved in this project. For this reason, further discussion will center on the Product Group and Operations organizations.

The Operations organization is made up of many groups with differing responsibilities. Some of the groups within the Operations organization at Dell include:

- Production responsible for assembling and shipping products
- Process Engineers responsible for factory equipment and workflow
- Product Engineers responsible for new product introductions
- EHS responsible for improving safety, health, and the environment

The groups within the Product Group involved with this project are the product designers and the component engineers. The product designers are responsible for in-house mechanical design and component layouts within the new systems. The component engineers are responsible for selecting and qualifying the purchased components that go into the new computers.

Each group associated with this project, or stakeholder, has its own set of metrics upon which its success is measured. These metrics are shown in Figure 2 below.

Stakeholder	**Key Metrics**
Production (Factory Associates)	Volume, Workmanship, Cost Per Box, Ship to Target
Product Group (PG)	Time to Market, Cost Per Box
Process Engineering	Equipment Cost, Performance, and Installation Speed
Product Engineering	Speed of New Product Introduction, Workmanship
Environmental Health and Safety (EHS)	Injury Rates, Days of Job Restriction and Away from Work

Figure 2: Stakeholder Metrics

Incorporating ergonomics outside of EHS is a challenge because of each group's unique metrics. There exists a perception that safety decisions do not align with the current metrics of other organizations. For this reason, this project needs to focus on metric alignment and management support. This idea is apparent in the project strategy and the need for quantitative data and cost information.

Cultural Environment

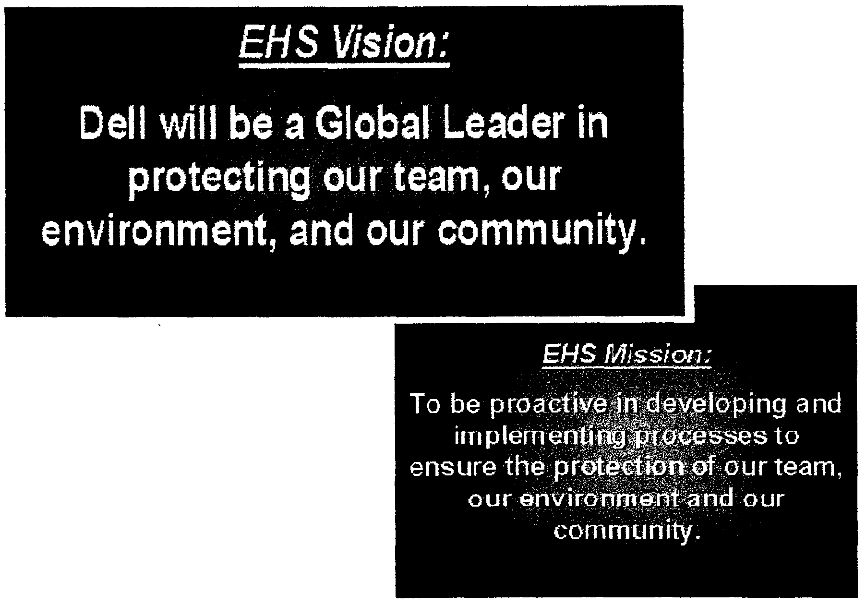
Dell has been very successful in the years since it entered the computer industry. Much of this success is a result of Dell's business strategies and metric driven organizations. Additionally, the culture at Dell should be taken into account when exploring the company and its modes of operation.

Competitive, fast-paced, and challenging are a few words to summarize Dell's culture. Dell requires resourcefulness and employees must do whatever it takes to get the job done. Regardless of the individual means necessary, those that meet their individual metrics are rewarded.

To reach middle to upper management, a strong informal network is necessary. There is a considerable amount of after-hours socialization between Dell employees. The informal network is strengthened by friendship and outside interaction. Those wanting to climb the ranks at Dell recognize and utilize the power of Dell's informal network.

Many companies have a strong safety culture. This means that safety is a top priority in any decision. Examples include decisions involving machine design, productivity goals and employees not being allowed to move their own office furniture. As a relatively young company, Dell is continuing to shape their safety culture.

Currently at Dell, efforts are underway to improve and strengthen the safety culture. As stated by one executive in June of 2003, "18 months ago, Dell woke up to the realization that Dell needs to be the leader in EHS." Dell expanded its EHS department while creating a new vision and mission statement for the organization as shown in Figure 3. They have been making great strides in improving the safety of Dell employees.



EHS Vision:

Dell will be a Global Leader in protecting our team, our environment, and our community.

EHS Mission:

To be proactive in developing and implementing processes to ensure the protection of our team, our environment and our community.

Figure 3: The Vision and Mission of EHS at Dell

Dell is a global company with sites in many states and countries. With that, there are cultural differences between locations. The above cultural observations are the result of my time in the Austin, Texas facility and a short visit to the Nashville, Tennessee facility.

Dell has a clear business strategy centered on its direct model. The pace at Dell is fast and the main focus is on cost reduction. Its organizational structure is divided mainly by business function. Each organization and individual employee has clear metrics that drive behaviors and decisions. Overall, the culture at Dell is competitive and challenging. With these ideas in mind, a project strategy was developed.

CHAPTER 3: PROJECT STRATEGY

Given Dell's business strategy, organizational structure, and culture, the project strategy selected to influence ergonomic decisions was a proactive approach that included creating awareness. The overall project began with evaluating the impact of ergonomics in the factory, identifying the greatest opportunities for improvement, developing ergonomic guidelines and evaluation tools for product and process design, and laying out implementation plans with an ultimate goal of creating value for Dell by reducing injuries, improving the safety of Dell employees, and generating cost savings. Figure 4 below describes this general project strategy.

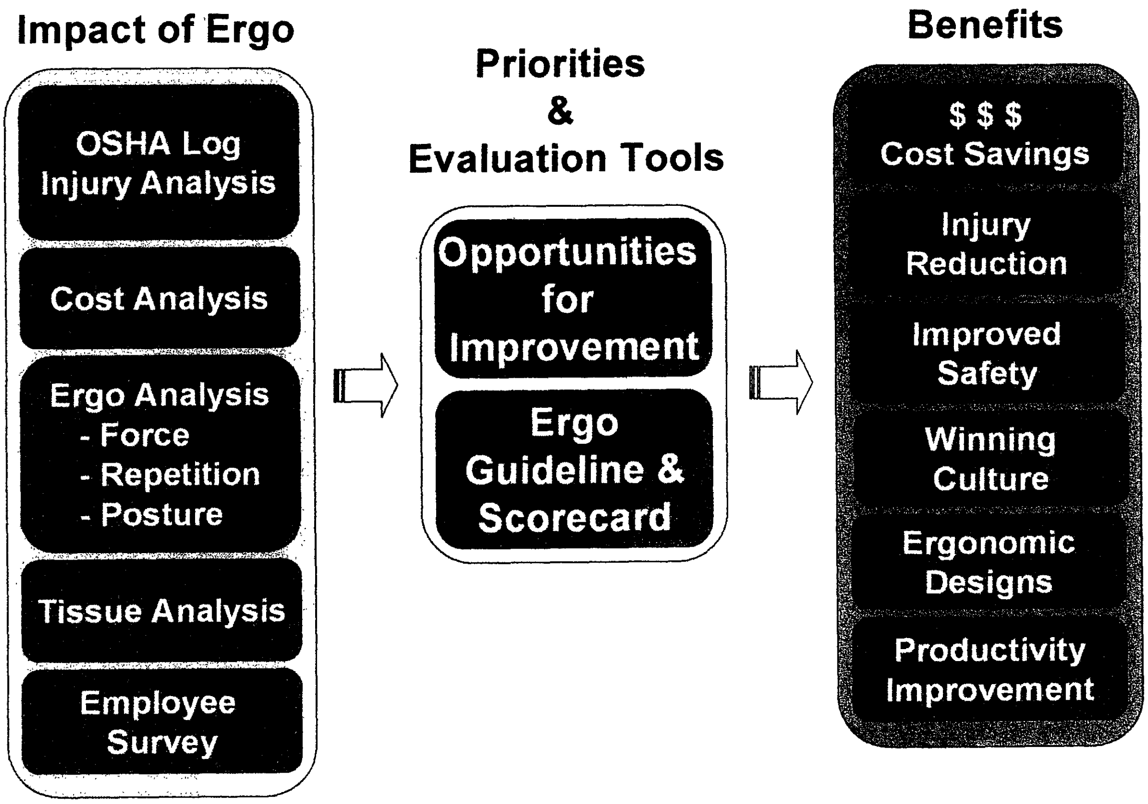


Figure 4: Project Strategy

The first few months of the project focused on performing analysis and data collection. The second half of the internship concentrated on the generation of evaluation tools; ergonomic guidelines and design scorecards. The guidelines were based on analysis findings and industry research performed. The analysis centered on Dell America's desktop manufacturing sites. These two sites are TMC in Austin, Texas and EG1 in Nashville, Tennessee.

Data collected and incorporated into the guidelines included:

- a detailed analysis of OSHA incident logs for 2002 and 2003
- force and motion repetition measurements for a variety of systems, components and tasks
- build associate survey results

The guidelines and tools generated are in two forms: a set of interactive ergonomic scorecards and a collection of general ergonomic guidelines.

Once the analysis was performed and the guidelines and scorecards were developed, project efforts aimed to communicate the project findings and solidify implementation of the design tools. The implementation phase of the project is still underway at Dell through the continued work of EHS. It is important to note the significance of management support to enable implementation across various organizations. Because the strong individual metric structure that is in place doesn't include specific ergonomic metrics for all employees, this project must have strong and visible management support in order to be successful.

Now that the project strategy and implementation steps have been presented, the discussion will focus on the results of the ergonomic analysis.

CHAPTER 4: ANALYSIS

There were multiple goals for the analysis portion of the project. This included quantifying the occurrence of ergonomic injuries, demonstrating the financial impact, sharing the views of factory associates and collecting data for the design scorecards. Ultimately, the objective of the research was to demonstrate the value and importance of ergonomics to Dell such that others will consider ergonomics in their decisions.

Ergonomic Injury Analysis

The first analysis was targeted to understand what percentages of the injuries occurring at Dell were ergonomic in nature. This was not a simple task to perform. In order to simplify the task somewhat, only the events that were considered OSHA recordable injuries were evaluated. This includes any injury that required medical treatment, restricted work activity, or time away from work. The OHSA logs were reviewed injury by injury. The injury descriptions were analyzed to determine whether or not the incident was ergonomic in nature. Acute events, such as trips, slips, cuts and falls were not classified as ergonomic injuries. Injuries resulting from repetitive motions of pushing, pulling, lifting, and building were considered ergonomic in nature. In addition, injuries resulting from awkward postures were classified as ergonomic injuries. The task of injury classification was time consuming because the injury reporting languages and styles were not consistent. To improve this process, recommendations were made to use common language in the description of injuries in the logs. This will streamline the data entry process and improve data management capabilities. Below in Figure 5, results for calendar year 2002 and the first half of 2003 indicate that ergonomic injuries make up a large percentage of Dell's OSHA recordable injuries.

January – December 2002	TMC	EG1
OSHA Incidents	[redacted]	[redacted]
Ergo-Related OSHA Incidents	[redacted]	[redacted]
% Ergo-Related OSHA Incidents	**64%**	**77%**

January – June 2003	TMC	EG1
OSHA Incidents	[redacted]	[redacted]
Ergo-Related OSHA Incidents	[redacted]	[redacted]
% Ergo-Related OSHA Incidents	**70%**	**73%**

Figure 5: OSHA Incidents at TMC and EG1 Factories

Reviewing the OSHA logs to assess the ergonomic situation at Dell's TMC and EG1 facilities relies heavily on the logs' ability to convey an accurate description of the situation. This analysis assumes that each incident is work-related. Also, the analysis cannot account for any injuries that are not reported. The issue of non-reporting is possible in all work environments. A strong safety culture and enforced safety policies reduce the potential occurrence of non-reported injuries. Because ergonomic injuries occur over time, it is often difficult for an injured employee to recognize when they have an injury. This may add to the complexity of accurate injury reporting.

The next task in the analysis was to understand where in the factory ergonomic injuries were occurring. Quantifying incidents by location helped demonstrate where to initially focus exploration into ergonomic injuries. In Figure 6, it is clear that a majority of the ergonomic injuries are occurring in the build area. This is the process step where the computers are assembled. The chassis, or housing of the computer, is met with the required components (i.e. hard drives, memory, CD/RW drives, etc.). A build associate's responsibility is to assemble the computer. They build one computer and another is waiting to be assembled. With required breaks, they perform this manual function for 8, 10, or 12 hour shifts. This role has the greatest number of ergonomic injuries.

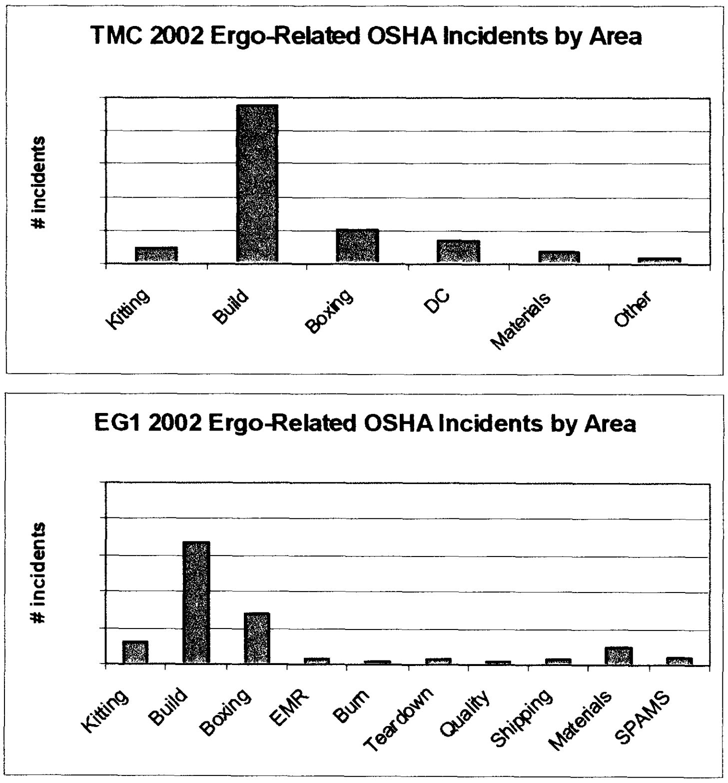


Figure 6: Ergonomic Injuries by Factory Area

It is also important to note that a large percentage of Dell's factory employees work in the build area. This is an additional contributor to the high number of injuries in this area. To increase the validity of the results of this study, conversion of these injury numbers to rates per employee is preferred.

In order to prevent future ergonomic injuries, it is necessary to understand the specific actions that are causing injury. This is challenging due to the complicated nature of ergonomic injuries. Despite this, the OSHA recordable injuries were separated by the causal actions specified on the OSHA logs. The results are shown in Figure 7. Looking at both TMC and EG1 facilities for the calendar year 2002, the general action of building was the most common specified action causing injury. Unfortunately, because the detail and quality of the data in the OSHA logs is limited, there isn't any way to breakout the casual actions in the build tasks in greater detail. To probe for further insight to the contributing factors in the build area, a build associate survey was conducted. Results of this survey are shared later in the analysis section. Lifting, bending, pushing and pulling were the next most commonly specified actions causing ergonomic injuries.

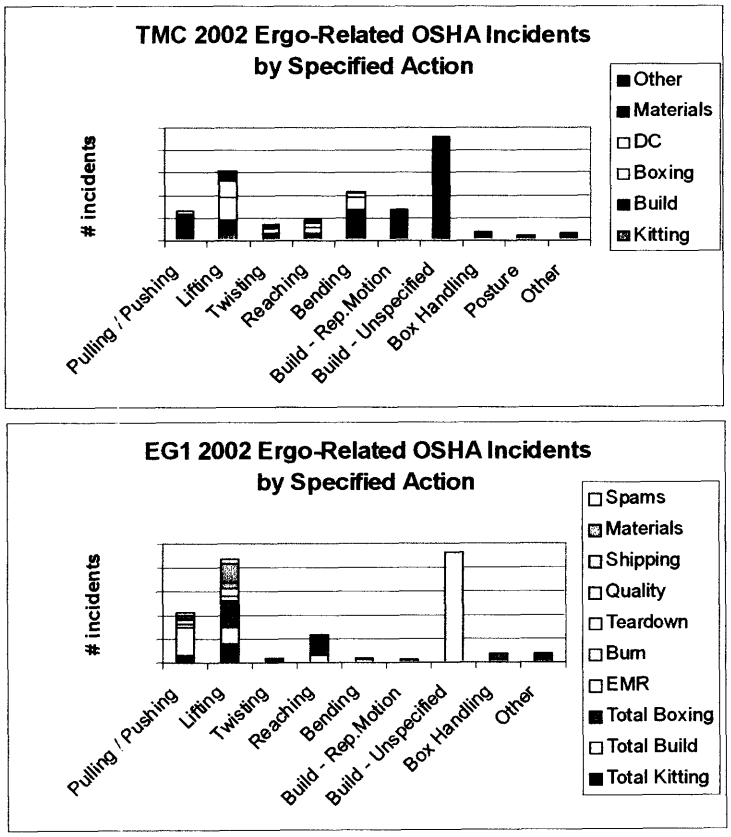


Figure 7: Ergonomic Injuries by Specified Action

Looking further at the ergonomic injury data, Figure 8 highlights the body parts (BP) in which the ergonomic injuries have occurred. It is interesting to recognize the differences between the two facilities. The back was the BP in TMC that was most often injured. In EG1, there were half as many back injuries. Exact reasons for this are not completely understood. Perhaps it has to due with differences in factory layout, compliance with lifting policies, diagnosis, or willingness to report injuries. The next highest injured BP, the wrist, had a similar number of injuries in both factories in 2002.

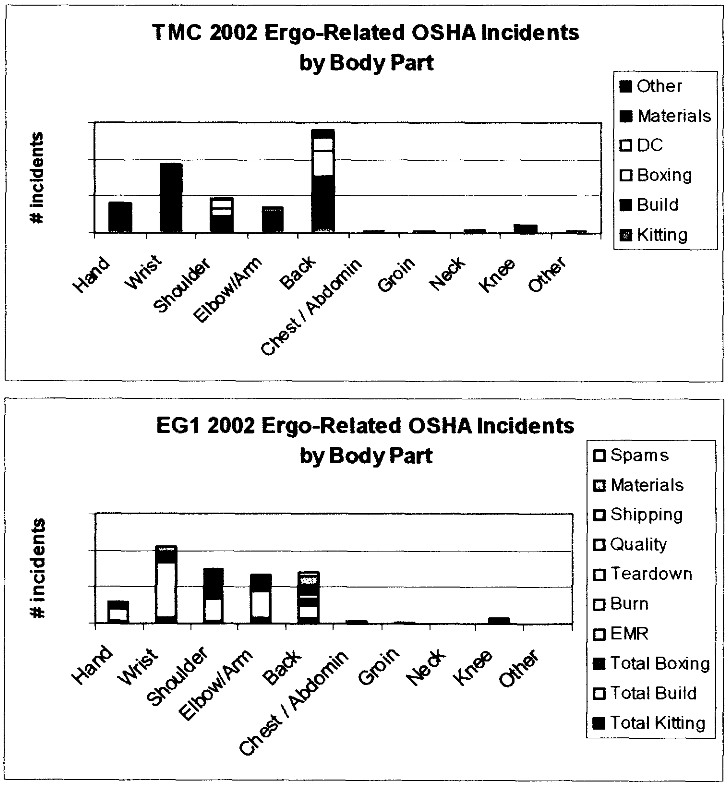


Figure 8: Ergonomic Injuries by Body Part

In addition to understanding ergonomic injuries in terms of factory area, specified action and body region, it is also important to explore their contribution towards Dell factory employees' days of job restriction and lost work. Because of the severity of many ergonomic injuries, it is not surprising that a large number of the days on job restriction and away from work are the result of ergonomic injuries. In both factories, ergonomic injuries in build resulted in the greatest number of days on job restriction. Build ergonomic injuries also contributed highly to the lost work days. Over 50% of each factory's total lost days, including those ergonomic and non-ergonomic in nature, were a result of ergonomic injuries in the build area. Figures 9 and 10 further demonstrate the ergonomic impact to days on job restriction and away from work.

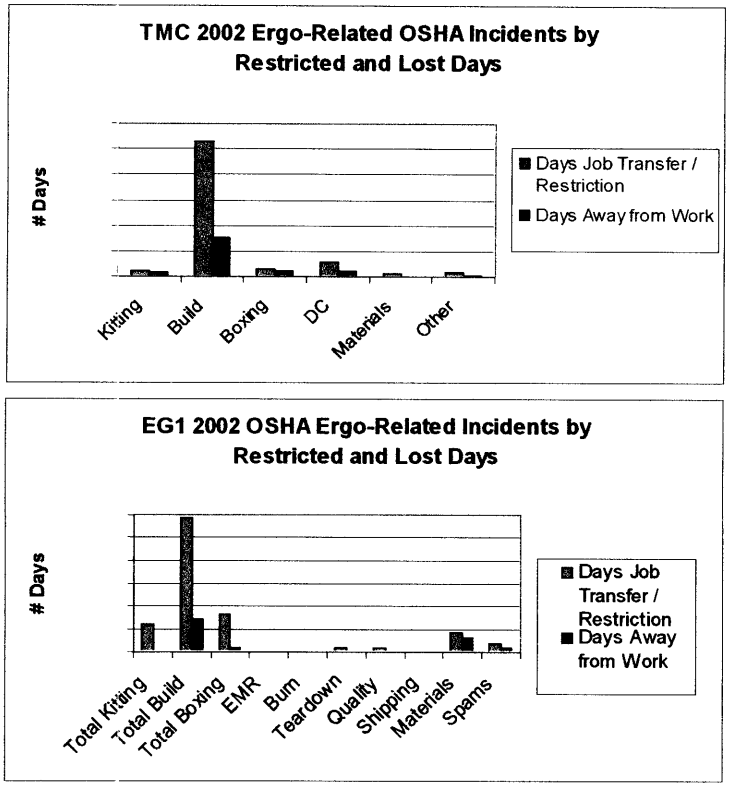
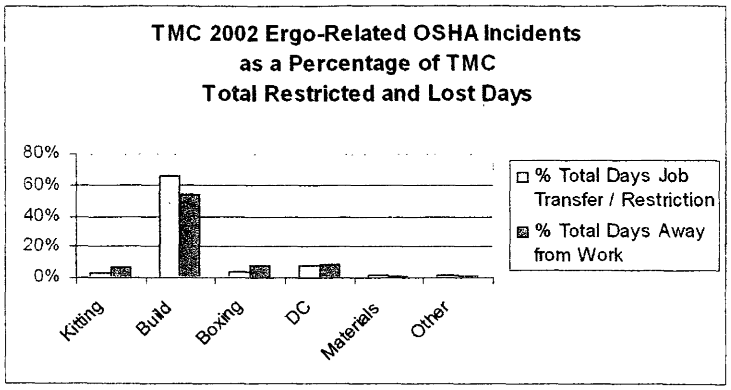


Figure 9: Job Restriction and Lost Work Days Due to Ergonomic Injuries



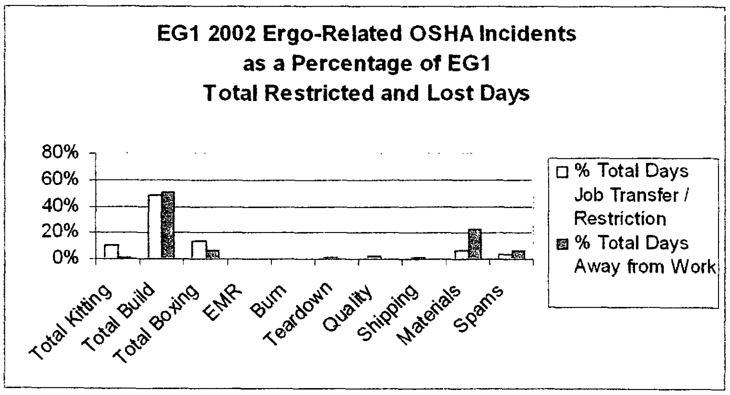


Figure 10: Ergo Injuries as a Percentage of Total Job Restriction and Lost Work Days

Through the evaluation of the ergonomic injuries documented on the OSHA incident logs for the TMC and EG1 desktop manufacturing facilities, a greater awareness and understanding of the impact of ergonomics was generated. Clearly, most of Dell's injuries are ergonomic in nature. Building, lifting, pushing, pulling and bending are the actions causing a majority of the injuries. The greatest number of ergonomic injuries occurs in the build area. These ergonomic injuries in build contribute significantly to Dell factory's total days on job restriction and total days away from work.

After quantifying the number and percentage of ergonomic injuries in Dell's factories, it is natural to inquire of the number and percentages of other computer firms. Unfortunately, ergonomic injury data is not easily accessible for other firms. Literature reviews indicate that it isn't uncommon to have 60% of injuries associated with ergonomics (Document #705011). General recordable injury rate data however is available by industry SIC code. Dell Inc. has an SIC code of 3571, Electronic Computers. The industry average recordable incident rate is 1.8. The incident rate approximates the number of injuries per 100 employees per year.

Cost Analysis

The next phase of the ergonomic analysis was to look at the financial impact of ergonomic injuries on Dell's factory floor. The prime motivator for this effort is Dell's strong cost focus. Problems that have cost numbers associated with them get greater focus and credibility at Dell. To that, putting cost data to ergonomic injuries was not a trivial task.

Working with Risk Management, cost data was collected for each OSHA recordable injury occurring in 2002 at the TMC and EG1 facilities. The cost data available included medical costs, worker's compensation, wages paid on lost days, and incidentals associated with each case. One metric that is very common at Dell is Cost Per Box (CPB). This measurement calculates an issues individual cost contribution to each computer manufactured. At Dell, CPB is a quick metric to access the impact of a project's potential contribution. For this reason, it was critical to get a cost estimate for ergonomic injuries in terms of CPB. This was achieved by obtaining data on the number of units built in the calendar year of 2002. Also, knowing the breakout of injuries by area, CPB numbers for ergonomic injuries were able to be determined for each factory area. The results of the ergonomic cost analysis are presented in Figures 11 and 12. In order to protect confidential information, the actual numbers are disguised and only relational comparisons are given. For example, the CPB of ergonomic injuries in TMC was $ x in 2002. The CPB of ergonomic injuries in EG1 was twice that of TMC, $ 2.0x.

Ergonomic Cost Analysis - 2002		
Factory	CPB	Avg. Medical Cost/Case
TMC	$ x	$ y
EG1	$ 2.0x	$ 1.8y

Figure 11: The Cost of Ergonomics in 2002

Factory	Total Ergo Cost	# of Systems Built
TMC	$ t	1.4s
EG1	$1.5t	s

Cost Per Box (CPB) By Area – 2002							
	Overall	Kitting	Build	Box	DC	Matls	Other
TMC	$ 16a	$ a	$ 10a	$ 6a	$ a	$ a	$ a
EG1	$ 32a	$ 3a	$ 17a	$ 6a	NA	$ 3a	$ 4a

Figure 12: The Cost of Ergonomics by Factory Area in 2002

It is important to note that the cost data collected does not include any costs associated with productivity or quality losses as a result of ergonomic injuries. In addition, it isn't possible to put a financial cost on the pain, stress, and sometimes life-changing effects an ergonomic injury can cause to the individual employee and their family.

In looking at the average cost per case presented in Figure 11, it is important to note the difference between the two factories. There are a few possible reasons for this difference. The two factories are in different states. Settlements allowed in Tennessee could have increased the average cost per case. Also, the number of severe cases reported was higher in EG1. In addition, the contract companies that manage the injury cases for Dell are different at the two sites. A different approach to injury management could account for differences in the case costs.

Regardless, both the quantified and un-quantified costs associated with ergonomic injuries at Dell's factories are significant. Reducing injuries will continue to be important for Dell as it aims to improve the safety of its employees and reduce the costs associated with manufacturing computers.

Tissue Analysis

An additional part of the analysis portion of the project was to take an in-depth look at the ergonomic injuries occurring in Dell's factories. More specifically, the analysis involved exploring the incidents by the nature of injury (NOI) and gaining an understanding of the internal tissue response to these injuries. In Figure 13, the ergonomic OSHA incidents for TMC and EG1 that occurred in 2002 are presented by nature of injury.

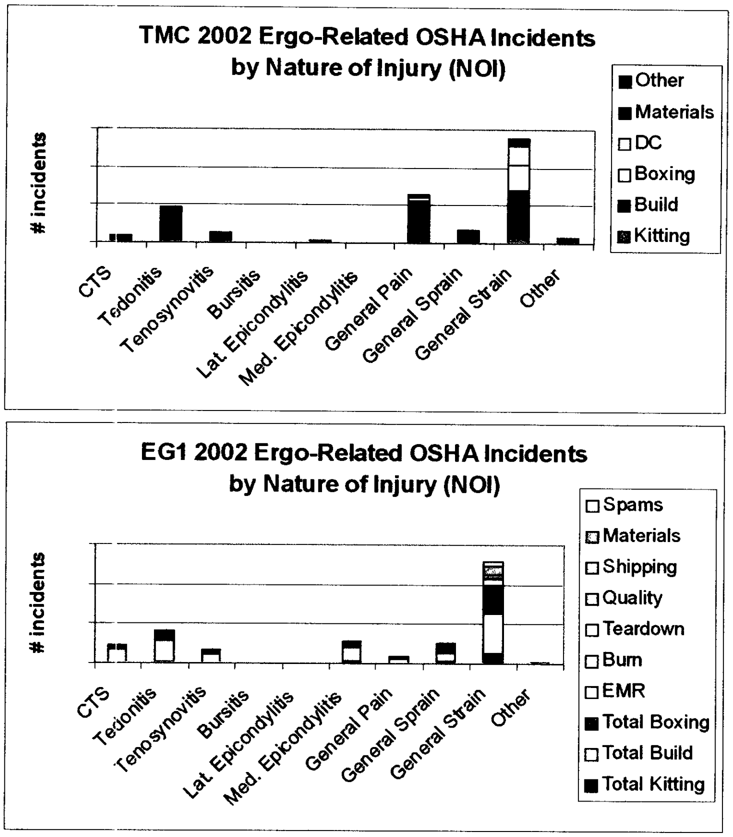


Figure 13: Ergonomic Injuries by Nature of Injury

It is observed that strains, tendonitis, and general pain were the most common ergonomic medical issues. This portion of the analysis section will discuss the tissues associated with these injuries, the functions of these tissues, the tissue damage occurring, and the tissue response and its healing capabilities.

Ergonomic injuries are often referred to as musculoskeletal disorders. These injuries are the result of damage to connective tissue, muscles and nerves within the body. At Dell, the most commonly diagnosed ergonomic injury is a strain. Strains related to ergonomic injuries most often occur in muscles or connective tissues.

Striated (or skeletal), cardiac, and smooth are three types of muscle tissue. Most ergonomic injuries involving muscle occur in skeletal muscles. The main function of skeletal muscles is to enable locomotion and posture (Kroemer, 65).

When ergonomic injuries involve connective tissues, ligaments and tendons are usually the tissues involved. Ligaments and tendons provide stability and guidance within the musculoskeletal system (Kumar, 27). The specific functions that ligaments perform include attaching articulating bones to one another across a joint, guiding joint movement, maintaining joint congruency, and acting as a strain sensor (Kumar, 27). Functions of tendons include attaching muscle to bone and transferring forces between muscle and bone (Kumar, 27).

The composition of muscles, ligaments, and tendons are shown below.

Components of muscle:

Water	75%
Protein	25%
Other constituents	5%

Other constituents includes fats, glucose, glycogen, pigment, enzymes and salt
(Kroemer, 65)

Components of ligaments and tendons:

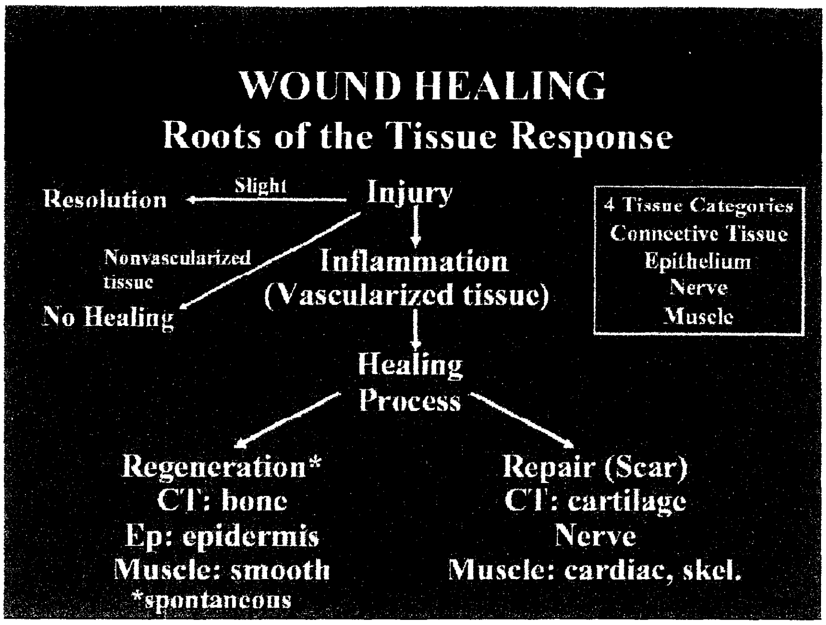
Water	up to 60%
Collagen	70-80% of fat-free dry weight
Type I (predominant)	
Types III, VI, X, XII (minor)	
Proteoglycans, glucoproteins (fibronectin), elastin	
Cells (fibrocytes)	

(Kumar, 29)

Now that the most common tissues affected in ergonomic injuries have been identified and discussed, it is important to look at the damages occurring. First, muscle tissue damage is explored. Injury to muscle, as with most injuries in general, can vary in terms of severity. The first sign of potential muscle injury is muscle fatigue. Muscle fatigue occurs after prolonged and strong contractions. Extreme fatigue can lead to a muscle's inability to get necessary energy and to remove metabolic byproducts. If this fatigue occurs, a person must rest before being able to resume the tasks they were performing. This rest is necessary for muscle recuperation. The posture in which work is performed is also thought to affect the speed at which muscle fatigue occurs (Kroemer, 66). If repetitive fatigue is induced, a muscles ability to recuperate is jeopardized. This fatigued muscle can subsequently be injured in two ways. The repetitive actions can worsen to an irreversible state or a sudden action can cause a catastrophic injury within the muscle, such as a large tear.

Ligament and tendon injuries also occur in two similar categories. They are referred to as repetitive micro-trauma or macro-trauma (Kumar, 50-52). Just as with muscle the severity of these injuries varies with each event.

A wound's ability to heal and type of healing depends on the injured tissue. The following figure, Figure 14, depicts wound healing of various tissue categories. It is important to note that skeletal muscle and the connective tissues of ligaments and tendons do not regenerate. Instead of regenerating new tissue with similar composition and function, these tissues injured in ergonomic injuries are repaired with scar tissue.



WOUND HEALING

Roots of the Tissue Response

Resolution ← Slight — Injury

Nonvascularized tissue

No Healing

Inflammation

(Vascularized tissue)

Healing Process

Regeneration*
CT: bone
Ep: epidermis
Muscle: smooth
*spontaneous

Repair (Scar)
CT: cartilage
Nerve
Muscle: cardiac, skel.

4 Tissue Categories
Connective Tissue
Epithelium
Nerve
Muscle

(Adapted from Spector & Yannas)

Figure 14: Tissue Response to Wound Healing

To further describe the healing response of skeletal muscle, ligaments and tendons, the following step-by-step account can be generated.

Step 1: *Bleeding and Inflammation*
Bleeding and inflammation occur due to the presence of vascularized tissue. Bleeding occurs as a result of blood vessels being torn and an inflammatory response takes place. In addition, pain begins to occur at this stage. As a response to bleeding, platelet and fibrin clots are produced. In addition, cytokines and growth factors are released to encourage and control inflammation.
Also at this time, inflammatory cells and fibroblastic scar cells are present. This first step of injury response occurs in the first hours of healing and can last for a few days.

Step 2: *Scar Proliferation*
The second step of the healing process related to ergonomic injuries is scar proliferation. In this stage, cells known as scar fibroblasts proliferate. Additional cells, such as macrophages and other inflammatory cells, work to remove the damaged tissue and debris. As a final activity in this step, a disorganized scar matrix is formed. This scar proliferation step occurs in the first few weeks of healing.

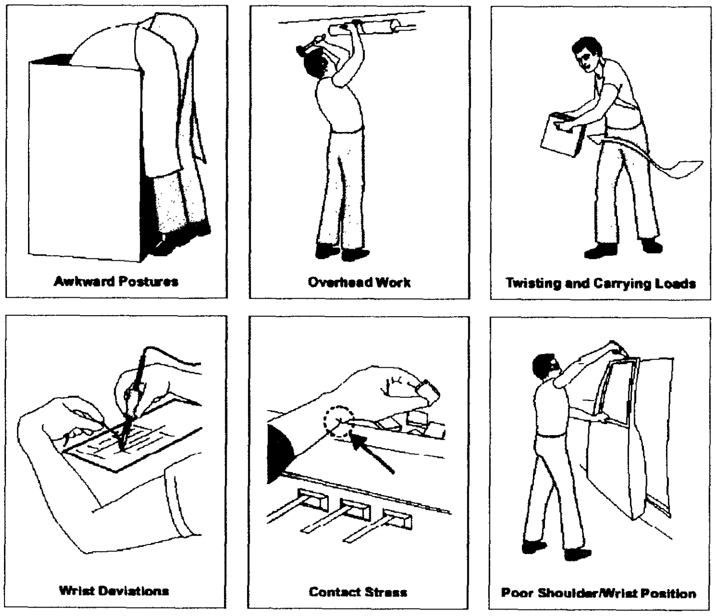
Step 3: *Scar Remodeling*
The final stage of the healing process is scar remodeling. In this stage, flaws within the disorganized scar matrix are infiltrated with collagenous matrix. Collagen fibers are reorganized, become less random, and are more aligned to function. Unfortunately, as with all scar healing processes, tissue composition and function are never restored to their original states. The scar remodeling phase occurs in the first year of healing.

(Kumar, 52)

Ergonomic injuries can often be devastating because they often heal through scar repair. These tissues do not regenerate and original function of this tissue is often not possible. One example of the deterioration of function is indicated in the study of the medial collateral ligament (MCL). Studies show that even one year after injury the ultimate tensile strength of a rabbit or canine MCL is only 50-70 percent of that of a normal ligament (Kumar, 52). Therefore, in order to prevent irreversible damage, ergonomic injuries need to be prevented.

Factory Ergonomic Analysis

After gaining an understanding of the prevalence and cost of ergonomic injuries on the factory floor, it was important to get out on the factory floor and evaluate the ergonomic aspects of the many tasks on the factory floor. Though ergonomic injuries are often the result of more than one factor, in order to reduce the risk of injury it is necessary to address each factor separately. For this reason, this factory ergonomic analysis was broken up into three areas; force, motion repetition and posture. These three risk factors were selected because they are three of the greatest risk factors that Dell can influence in its factories. The data collected on force, motion repetition, and posture for each task was converted into individual scores that indicate ergonomic risk levels. The scores collected as a result of this factory analysis were critical in developing the ergonomic design scorecard that will be described later in this thesis. With the exception of a few side projects, the majority of the factory analysis was focused on the tasks in build area. In Figure 15, a few common ergonomic workplace issues are depicted.



(Adapted from Cohen, 21)

Figure 15: Ergonomic Workplace Risk Factors

Force Measurements

Many of the tasks in building a computer require the use of force. Because the build associates assemble multiple computers each day, lower required forces can significantly reduce the risk of injury. Prior to this project, the forces required to build computers at Dell hadn't been studied in great detail. In order to understand the forces used, measurements were taken. Some of the tasks measured include opening the chassis, installing a hard drive, inserting cables, and opening component packaging. Four ways in which forces are exerted include gripping, pinching, pushing with one finger, and pushing with multiple fingers. Some of the forces measured are shown in Figure 16.

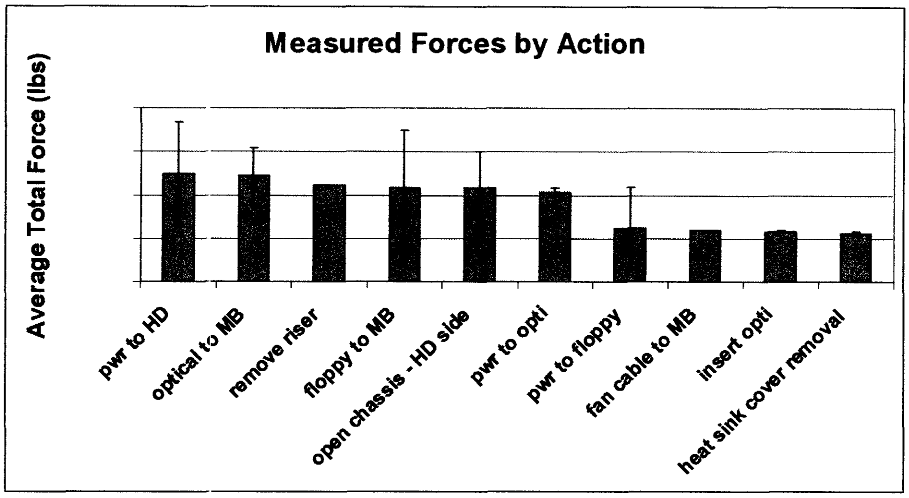


Figure 16: Forces Used to Assemble Computers

Most of the force measurements taken were done using Flexiforce™ Sensors and the Economical Load and Force (ELF™) System. The sensors are piezoelectric. Data is collected and stored on a computer. Sensors were placed on the hand, primarily on the finger tips. Different sensor positions were required based on the technique for performing the task. Multiple measurements were taken on a variety of systems. To reduce variability induced by the operator, the same employee took all the measurements. The Dell employee that assisted with the measurements had 5 years experience as a build associate and was currently in a role where he trained new build associates. He was consistent in his techniques and was very knowledgeable of the build process. In Figure 17, the piezoelectric sensors are shown. The photo on the left demonstrates measuring the force required to drive in a screw using a torque driver.

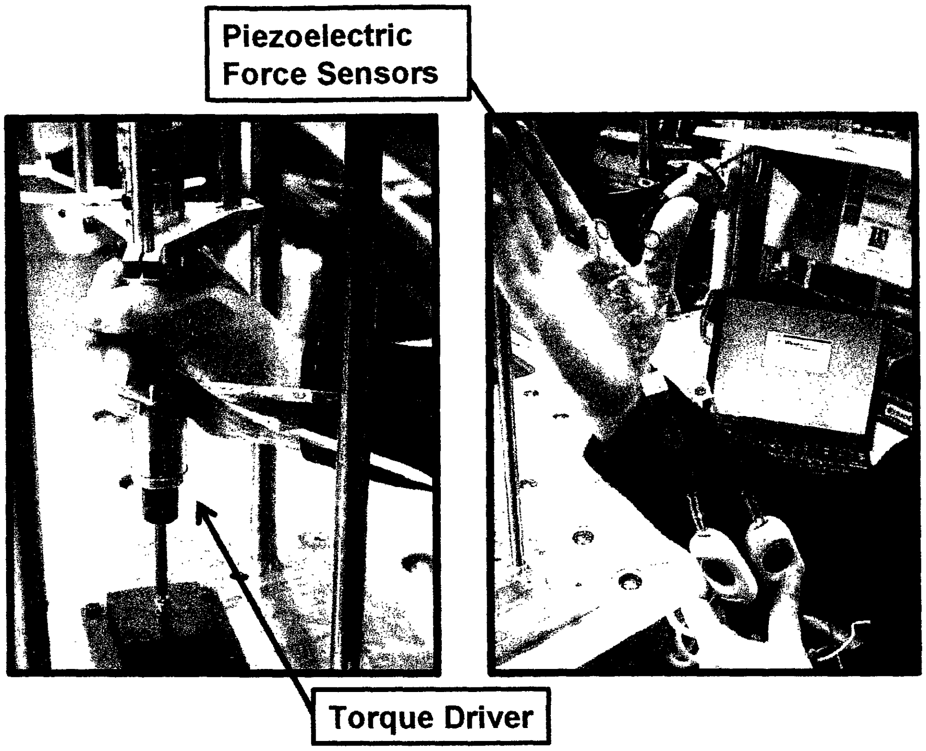


Figure 17: Force Measurements Using the ELF™ System

Because there exist the opportunity for error in the Flexiforce™ measurements, additional measurement techniques were explored. The following picture, shown in Figure 18, depicts an additional measurement technique that was used to evaluate forces in the build process. This second technique was performed on an Instron™ machine. The results measured using the second testing method indicated that the Flexiforce™ sensors, when calibrated prior to each use, were consistent with the results measured on the Instron™ machine.

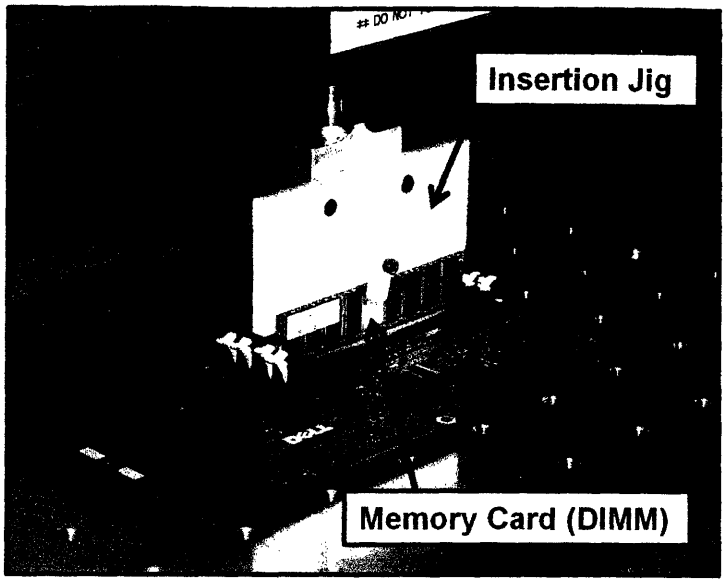


Figure 18: Force Measurements Using the Instron™

Much research has been done in determining the strength capabilities of humans. Strength studies performed by DTI were used to compare the forces measured on the factory floor to corresponding ergonomic risk levels. Based on the exertion type used and the guidelines available, the forces measured for each task were converted to risk scores ranging from 0 to 5. A score of 5 corresponds to a high ergonomic risk factor and 0 corresponds to a low ergonomic risk factor.

Repetition of Joint Motions

The next ergonomic risk factor evaluated in the build process was repetition of joint motions. The number of joint motions was counted for each action in the build process. Joint motions counted for each task included shoulder flexion and abduction, wrist movement, hand interface in the from of a grasp or pinch, finger key strokes, single actions of the finger, neck movement and rotation, back movement in the form of bending, lifting, twisting, reaching and lowering. As for the forces, measurements of joint motions were to be converted into risk scores. In order to be able to distinguish the complexity associated with different actions, the score remained the actual number of joint motions. It is desired to have lower joint motions to reduce the risk of developing an ergonomic injury.

Posture

Posture is the third factor explored in the build area. Ten aspects of the build workbench layout and computer design were identified as the greatest contribution to posture. Variables identified included bench height, chassis wall height, component spacing, component location, system weight, and locations of tools within the work station. Multiple studies were referenced when determining the ergonomic risk levels introduced as a result of these variables influencing posture in the build area. Again, as with force, the variables were given ergonomic risk level scores ranging from 0 to 5.

Build Associate Survey

The final portion of the factory analysis for this project involved collecting the opinions and improvement ideas of the build associates. As mentioned earlier, it is difficult to determine the exact cause or causes of ergonomic injuries because of their complex nature. For this reason, the analysis has involved many approaches. The build associate survey was developed to document and quantify builder preferences and ideas for improvement.

The survey was completed by build associates in TMC and EG1. Build associates from all lines and shifts were included. The survey was anonymous to encourage open and honest feedback. Ergonomics and safety were not included on the survey thus trying not to alter the ideas of the survey respondents. The survey was composed of ten multiple choice questions and three open-ended questions. The sample survey is found in Appendices 6 - 9. A total of 310 of Dell's build associates completed the survey. 275 of the survey respondents were from the EG1 facility and 35 were from the TMC facility. Because of the high participation at EG1, the data presented in this report will focus on the results from EG1.

The first few questions of the survey regarded tenure at Dell. It was determined that in EG1 39% of build associates have worked at Dell for 2-4 years. Likewise, 38% of the build associates have been working in the build area for 2-4 years. Figures 19 and 20 present additional data showing current build employees' years at Dell and years working in the build area.

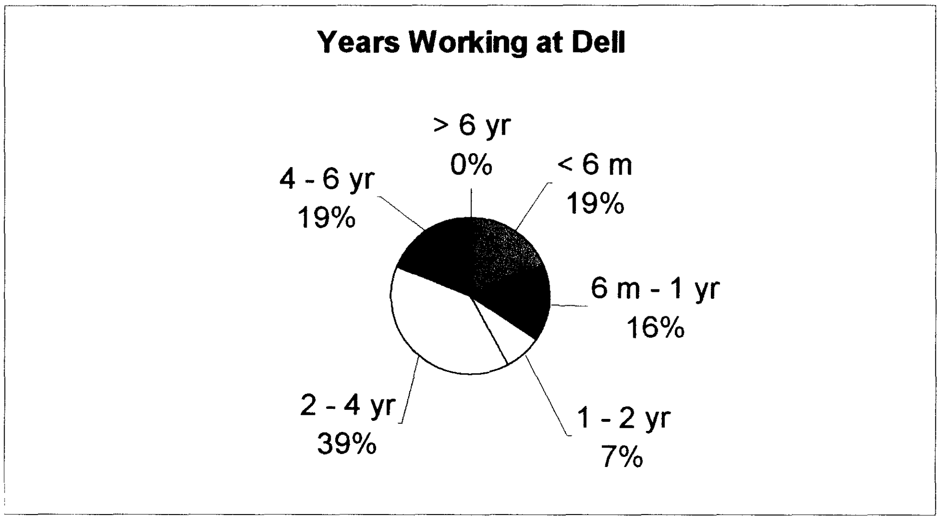


Figure 19: *Build Associate Survey* – Years Working at Dell

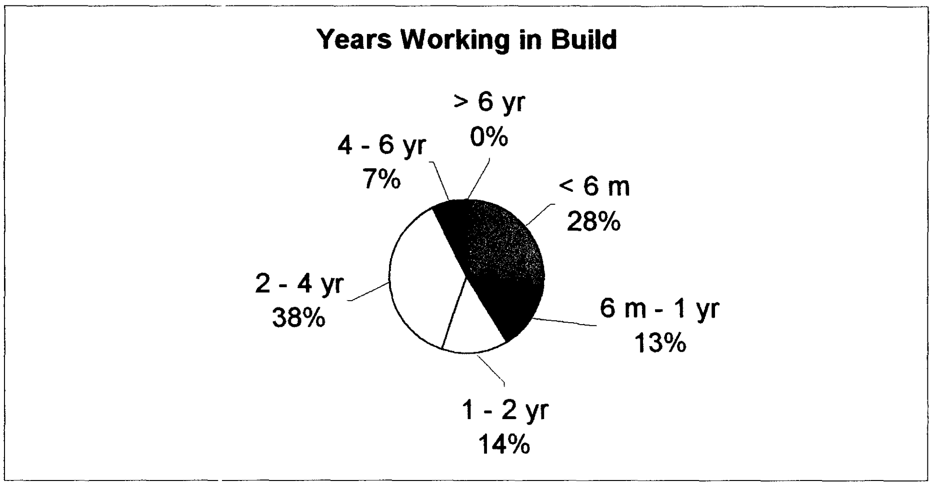


Figure 20: *Build Associate Survey* – Years Working in Build

In addition to getting some background information about each build associate, the survey was targeted to collect system preferences. Because employees do not all build the same type of computers (i.e. systems), it was necessary to collect information on which systems the employee had built. Once that was known the survey asked, "what system do you like best?" Builders in both EG1 and TMC had strong preferences. In EG1, 69% of those builders who have built "System B" selected it as the system they liked best. In TMC, 52% of those builders who have built "System G" selected it as the system they liked best.

Once the build associates indicated their favorite systems to build they were asked their reasons for liking a particular system. The results are shown in Figure 21.

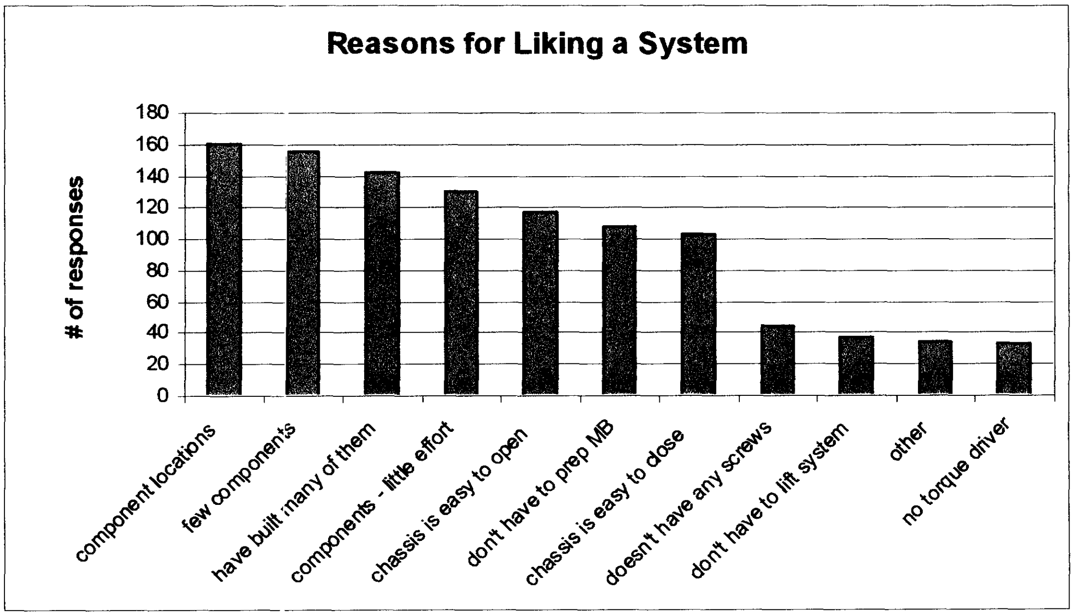


Figure 21: *Build Associate Survey* – Reasons for Liking a System

The survey also asked, "what system do you like least?" Builders in both EG1 and TMC had strong preferences. In EG1, 54% of those builders who have built "System I" selected it as the system they liked least. In TMC, 63% of those builders who have built "System F" configuration selected it as the system they liked least.

The build associates were then asked to indicate their reasons for disliking the system. Their selected reasons are shown in Figure 22.

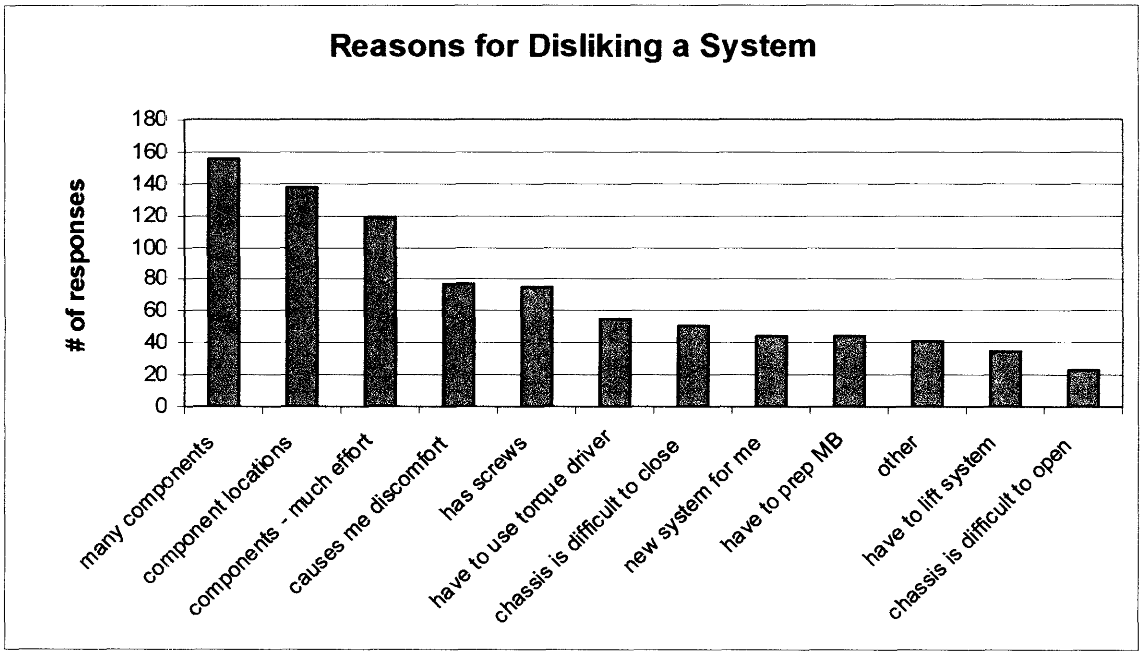


Figure 22: *Build Associate Survey* – Reasons for Disliking a System

To try to gain more insight into ease of building and identifying areas for improvement, the survey inquired about component installation. Figure 23 indicates the survey results when asked, "Which component is easiest to install?"

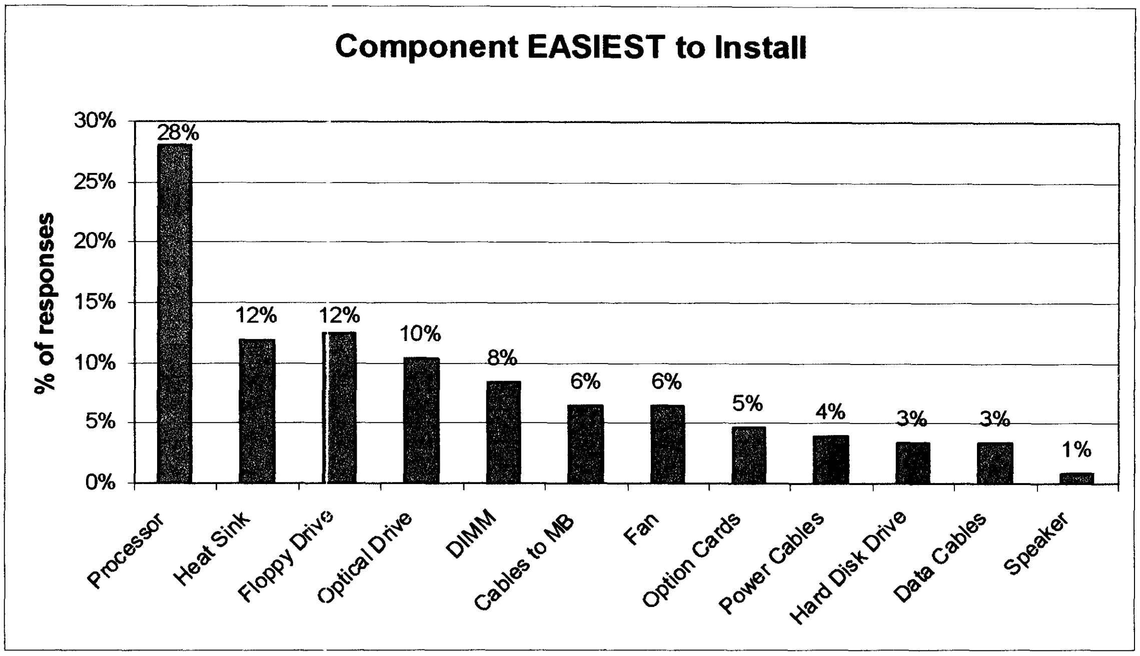


Figure 23: ***Build Associate Survey*** **– Easiest Components to Install**

Likewise, build associates were asked, "Which component is most difficult to install?" Figure 24 indicates the results of this question.

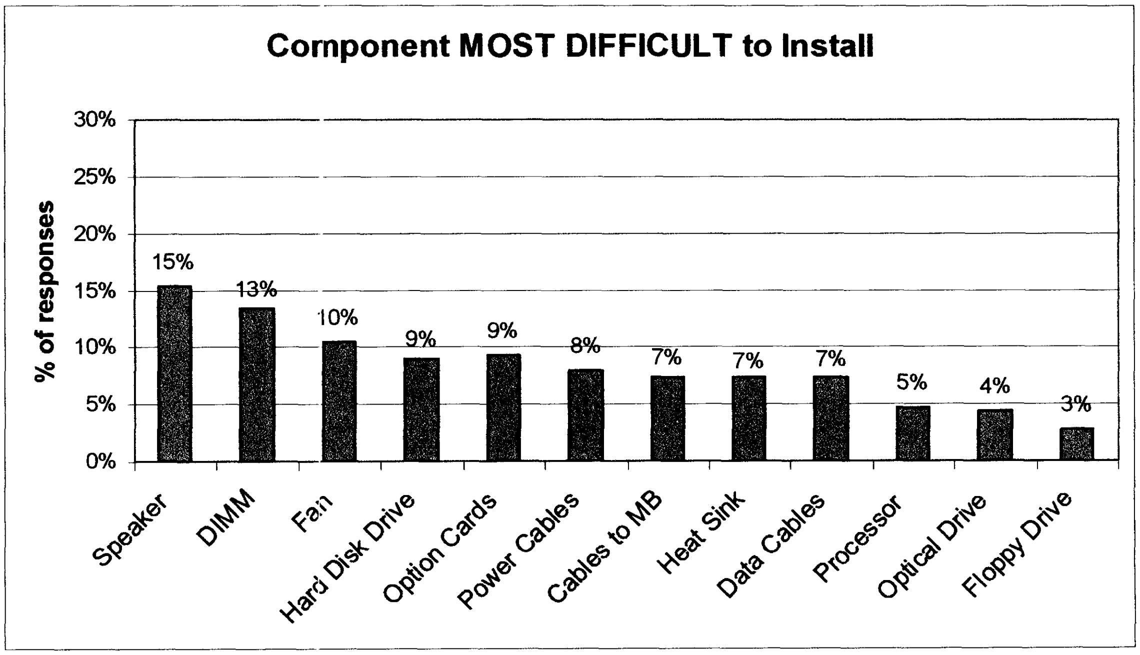


Figure 24: ***Build Associate Survey*** **– Most Difficult Components to Install**

The last three questions of the survey were open-ended to allow build associates to share their individual thoughts and ideas for improvement. Below is a summary of their responses.

When asked "What slows you down the most in build?" the most common responses were related to:

- Missing, wrong, and damaged parts
- Screws
- Opening bags and removing components from bags
- Waiting for systems
- Stickers and labeling

When asked "What could be done to allow you to build more easily?" the most common ideas involved the following:

- Improve component packaging
- More consistent part supply
- Adjustable workstations
- Easier component layouts

A great deal of information was collected as a result of the build associate survey. System preferences were quantified, reasons for system preferences were collected, ease of component installation was explored and build associates were able to share their ideas.

In general, build associates prefer systems that have fewer components, have components in locations they can access, and they are familiar with. The component that is easiest to install is the processor. The most difficult components to install are the speaker, DIMM and fan.

The information collected in the survey was used in a number of ways. The results of the survey were shared with the Product Group who is responsible for designing new systems and selecting new components. The results and ideas were shared with the EHS group and Operations organization. Based on the ideas documented in the survey, actions are already underway to implement some of the builders' ideas. Finally, the system preferences determined were used to validate the ergonomic design scorecard with the assumption that a preferred system is more ergonomic to build.

In the future, this survey should be administered again. It provides a quantitative means to determine system preferences and to track component improvements and issues. It is also a way to find quick wins to ease the build process, ultimately increasing productivity, improving build associate moral, and saving Dell money.

Through the results of all of the analysis, a greater understanding of the ergonomic situation and its impact at Dell's TMC and EG1 factories was gained. Information gathered was necessary to increase awareness and demonstrate importance. In addition, the information gathered plays a crucial role in the ergonomic design scorecards that were developed as a result of this project.

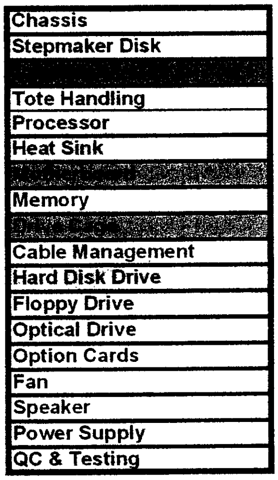
CHAPTER 5: ERGONOMIC DESIGN GUIDELINES & SCORECARDS

The next phase of the project was to develop ergonomic design tools for use by the product and process designers. This chapter will discuss the purpose of the design tools, the development, use, limitations and validation of the tools, and the steps for implementation.

Tool Development

Prior to development of these guidelines and scorecards, designers at Dell didn't have a means to evaluate the ergonomics of their projects. For this reason, the ergonomic design guidelines and scorecards generated through this project had the goals to provide a methodology and a tool set that could be used to evaluate and compare ergonomics of new and current systems and process designs.

The guidelines and ergonomic scorecards developed are focused on the desktop computers built in Dell's TMC and EG1 facilities. Additionally, the tools focus on the ergonomics in the build area of the factory. The first step in tool development was to segment the build process into steps or main topics. This segmentation is shown in Figure 25.



Chassis
Stepmaker Disk
[illegible]
Tote Handling
Processor
Heat Sink
[illegible]
Memory
[illegible]
Cable Management
Hard Disk Drive
Floppy Drive
Optical Drive
Option Cards
Fan
Speaker
Power Supply
QC & Testing

Figure 25: *Design Tools* – Build Process Segments

The next stage was to determine all possible actions associated with each of these process steps. It is important to note that the number and type of actions vary depending on the system design. An example of the possible actions associated with a system's chassis is shown in Figure 26.

Chassis
Turn to next chassis & return
Lift chassis to workstation & align
Pull chassis to workstation & align
Open clamshell chassis
Open chassis - hood side
Open chassis - HDD side
Set hood aside
Get & return scanner
Scan chassis
Rotate chassis - bezel facing builder
Pull chassis towards builder
Remove bezel
Hang bezel from above
Set bezel aside on workstation/tote
Turn to workstation & return
Grab bezel
Get chassis
Rotate chassis
Install bezel
Turn to workstation & return
Grab badge from workstation/tote
Get chassis
Install badge
Turn to workstation & return
Grab removable hood from side
Grab removable HDD from from side
Get chassis
Close clamshell chassis
Close removable hood chassis
Close removable HDD side chassis
Align chassis
Push onto conveyor

Figure 26: *Design Tools* – Possible Actions Associated with the Chassis

The next step in the development of the design tools was to identify the ergonomic risk factors associated with each action. As in the analysis portion, the risks evaluated were force, motion repetition and posture. This approach to action segmentation is shown in Figure 27.

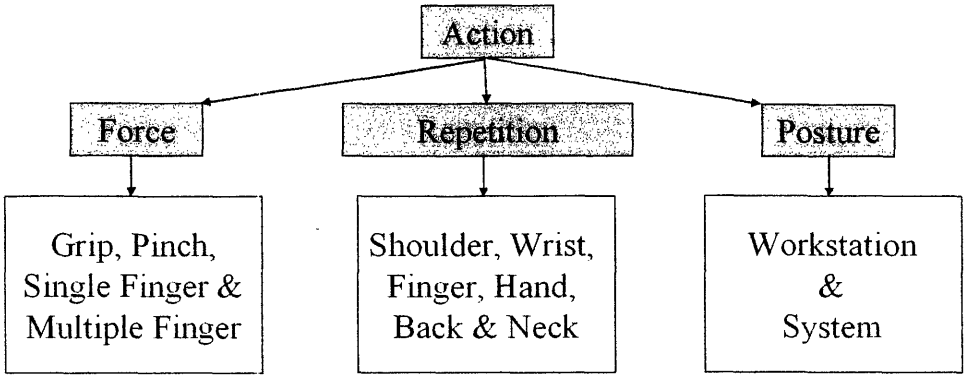
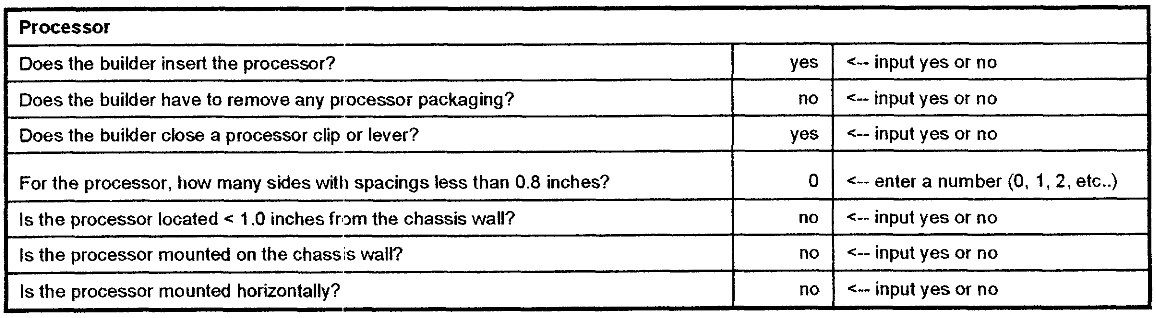


Figure 27: ***Design Tools*** **– Individual Action Analysis**

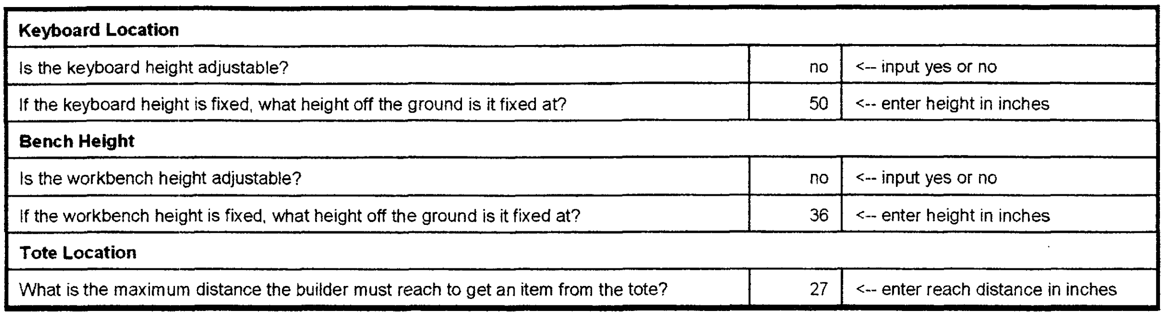
As mentioned earlier in the analysis section, each of these actions is given an ergonomic force score, a repetition score and a posture score. The score given to the action is based on input regarding the design and the ergonomic guidelines that were generated for force, motion repetition and posture. The ergonomic guidelines are found in Appendices 10-12.

The next stage was to develop a user interface to provide a designer a way to input the attributes of their design. The means in which the attributes of the new design are collected is with the use of Microsoft® Excel®. The designer answers a series of questions related to the system design and the process design. Examples of these questions are shown in Figures 28 and 29.



Processor		
Does the builder insert the processor?	yes	<-- input yes or no
Does the builder have to remove any processor packaging?	no	<-- input yes or no
Does the builder close a processor clip or lever?	yes	<-- input yes or no
For the processor, how many sides with spacings less than 0.8 inches?	0	<-- enter a number (0, 1, 2, etc..)
Is the processor located < 1.0 inches from the chassis wall?	no	<-- input yes or no
Is the processor mounted on the chassis wall?	no	<-- input yes or no
Is the processor mounted horizontally?	no	<-- input yes or no

Figure 28: ***Design Tools*** **– System Design Input**



Keyboard Location		
Is the keyboard height adjustable?	no	<-- input yes or no
If the keyboard height is fixed, what height off the ground is it fixed at?	50	<-- enter height in inches
Bench Height		
Is the workbench height adjustable?	no	<-- input yes or no
If the workbench height is fixed, what height off the ground is it fixed at?	36	<-- enter height in inches
Tote Location		
What is the maximum distance the builder must reach to get an item from the tote?	27	<-- enter reach distance in inches

Figure 29: *Design Tools* – Process Design Input

Using the ability to link cells and perform general algebraic functions in Excel®, each action is evaluated by the scorecard using the design guidelines and given an ergonomic score. Once the individual actions are scored, the results of each build segment are totaled. Finally, the scores for all the segments are combined into an overall system score. Examples of the force, motion repetition, and posture scoring of the chassis in a particular design are shown in the Figure 30.

Force Scoring:

	Input	Measured Force (lbs)	Grip Rating	Pinch Rating	One Finger Rating	Multiple Finger Rating	Total Ergo Score
Chassis							
Open clamshell chassis	1		0	0	0	3	3.00
Open chassis - hood side	0		0	0	2	0	0.00
Open chassis - HDD side	0		0	0	3	0	0.00
Remove bezel	1		0	0	0	3	3.00
Install badge	1		0	0	0	3	3.00
Close chassis	1		0	0	0	1	1.00
						Total Chassis Force Score	10

Motion Repetition Scoring:

	Input	**Shoulder** Flexion & Abduction	**Wrist** Movement	**Hand Interface** - Grasp & Pinch	**Fingers** - Key Strokes	**Fingers** - Single Action	**Neck** Movement & Rotation	**Back** - Lift, Bend, Twist, Reach & Lower	Total of All Motions
Chassis									
Open clamshell chassis	1	4	0	4	0	0	2	0	10
Open chassis - hood side	0	1	1	0	0	1	1	0	4
Open chassis - HDD side	0	1	1	0	0	1	1	0	4
Set hood aside	0	1	1	1	0	0	0	1	4
Get & return scanner	1	4	4	4	0	0	0	4	16
Scan chassis	1	1	1	1	0	0	1	0	4
Rotate chassis	1	4	0	2	0	0	0	0	6
Install bezel	1	4	2	2	0	0	2	2	12
								Total Chassis Motions	60

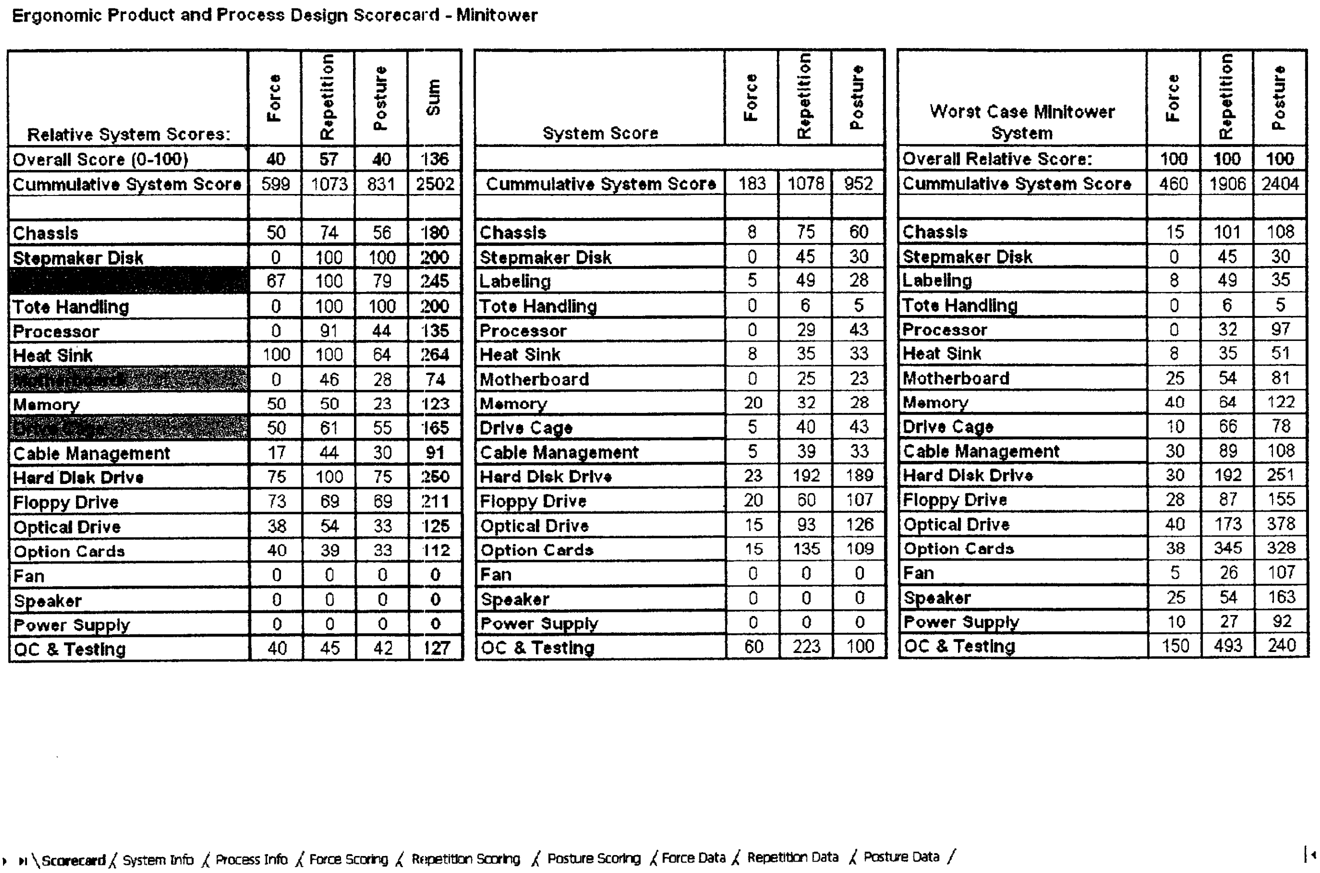
Posture Scoring:

	Input	**Bench Height**	**Chassis Wall Height**	**Component Spacing**	**Component Location**	**System Weight**	**Tote Location**	**Tote Handling**	**Keyboard Location**	**Driver Location**	**Trash Location**	**Scanner Location**	**Posture Total**
Chassis													
Open clamshell chassis	1	5.0	5.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	12.5
Open chassis - hood side	0	5.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Open chassis - HDD side	0	5.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Set hood aside	1	5.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Get & return scanner	1	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Scan chassis	1	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	10.0
Get chassis	1	5.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Rotate chassis	1	5.0	5.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	12.5
Install bezel	1	5.0	5.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	12.5
												Total Chassis Posture Score	**72.5**

Figure 30: Design Tools – Scoring

Once overall ergonomic scores for a new design were generated in terms of force, motion repetition and posture, it was necessary to determine a means in which to compare them. Because the types of systems that Dell offers vary in terms of complexity, it was important to segment them. It wouldn't have made sense to compare the ergonomics of a very complex system to that of a simpler system. The complex system would always have a worse score making ergonomic trade-off decisions very difficult. For this reason, three individual scorecards were developed, one for each class of system. The first scorecard is for the UltraSmall form factor class of systems. These are the most compact computers with the least number of components. The second scorecard is for the Minitower class of systems. These are the systems one would consider the average desktop. The final scorecard is for the Workstations. These are the largest and most complex systems.

In order to determine the impact of given ergonomic score. It was necessary to determine the worst possible ergonomic scores for systems in the three categories. The worst-case scores were determined by answering the input questions with the worse-case scenario for each system class. Scores for new designs are then compared to the worst-case system and given relative ergonomic scores. A relative ergonomic score of 100 is the worst possible score where as a relative ergonomic score of 0 is the best possible ergonomic score. A print screen of the ergonomic scorecard results for a representative system in the Minitower class is shown below in Figure 31.



Ergonomic Product and Process Design Scorecard - Minitower

Relative System Scores:	Force	Repetition	Posture	Sum
Overall Score (0-100)	40	57	40	136
Cummulative System Score	599	1073	831	2502
Chassis	50	74	56	180
Stepmaker Disk	0	100	100	200
[redacted]	67	100	79	245
Tote Handling	0	100	100	200
Processor	0	91	44	135
Heat Sink	100	100	64	264
[redacted]	0	46	28	74
Memory	50	50	23	123
[redacted]	50	61	55	165
Cable Management	17	44	30	91
Hard Disk Drive	75	100	75	250
Floppy Drive	73	69	69	211
Optical Drive	38	54	33	125
Option Cards	40	39	33	112
Fan	0	0	0	0
Speaker	0	0	0	0
Power Supply	0	0	0	0
QC & Testing	40	45	42	127

System Score	Force	Repetition	Posture
Cummulative System Score	183	1078	952
Chassis	8	75	60
Stepmaker Disk	0	45	30
Labeling	5	49	28
Tote Handling	0	6	5
Processor	0	29	43
Heat Sink	8	35	33
Motherboard	0	25	23
Memory	20	32	28
Drive Cage	5	40	43
Cable Management	5	39	33
Hard Disk Drive	23	192	189
Floppy Drive	20	60	107
Optical Drive	15	93	126
Option Cards	15	135	109
Fan	0	0	0
Speaker	0	0	0
Power Supply	0	0	0
OC & Testing	60	223	100

Worst Case Minitower System	Force	Repetition	Posture
Overall Relative Score:	100	100	100
Cummulative System Score	460	1906	2404
Chassis	15	101	108
Stepmaker Disk	0	45	30
Labeling	8	49	35
Tote Handling	0	6	5
Processor	0	32	97
Heat Sink	8	35	51
Motherboard	25	54	81
Memory	40	64	122
Drive Cage	10	66	78
Cable Management	30	89	108
Hard Disk Drive	30	192	251
Floppy Drive	28	87	155
Optical Drive	40	173	378
Option Cards	38	345	328
Fan	5	26	107
Speaker	25	54	163
Power Supply	10	27	92
OC & Testing	150	493	240

Figure 31: ***Design Tools*** **– Ergonomic Design Scorecard**

When looking at the scorecard above, the relative scores for force, motion repetition, and posture are shown in the table on the left. The individual system scores are shown in the middle table. The worst-case scores for the system class (in this case Minitower) are shown in the table on the right. In reviewing the overall relative scores, there are four overall relative scores ranging 0 to 100 for each of the three factors (force, repetition, and posture) and 0 to 300 for a relative sum score. In all cases, a lower number indicates a better ergonomic design. The relative ergonomic scores are also shown for each build process segment. Again, these relative ergonomic scores for force, motion repetition, and posture were generated by comparing the individual system score (middle table) to that of the worst-case system (right table).

Procedure for Use

The procedure for using the ergonomic scorecards is as follows:

Step 1: Scorecard Selection
Select a scorecard based on the class of system being evaluated. The options are UltraSmall, Minitower & Workstation

Step 2: Input Information
Complete or modify two worksheets within the Excel file-based scorecard. If the system or process is very similar to a current design, simply recall the current design and make the necessary changes. If the design is new, answer the questions regarding system and process design on the System Info and Process Info worksheets.

Step 3: Let Excel® Do Its Magic
Based on the information given in the System Info and Process info worksheets as well as the scoring guidelines for force and posture, the ergonomic scores are automatically calculated within the file.

Step 4: Comparisons
As described earlier, the scorecard provides a comparison to the worst-case system for each class of systems. In addition, further comparisons between systems can be performed as additional designs are scored for ergonomics using the tool.

Step 5: Evaluate
The final stage of the scoring is to use the tool to identify biggest design opportunities for improving the ergonomics. The build segments with the highest scores have the greatest opportunity for improvement.

Step 6: Document
As with any tool and data collection system, the tool isn't useful if others cannot utilize the information previously gathered. In order to get the most use out of this ergonomic design tool, it is critical to document the designs scored such that they can be used for future comparison and learning.

Limitations

A few limitations exist with the ergonomic guidelines and scorecard. The first limitation is that in determining a system ergonomic score force, motion repetition, and posture are equally ranked as risk factors. In reality, this may not be the case. The problem of determining risk factor weightings is very complex and not thoroughly understood. In addition, the contribution of these three attributes to cause injury may vary with each individual. Because of these complexities, force, motion repetition, and posture were kept separate and no weightings or combination effects were approximated.

The second possible limitation with the guidelines and scorecards has to due with the data gathering techniques used. There exists some measurement error with the use of the Flexiforce™ sensors and the ELF™ system to obtain the force measurements. In addition, the motion repetition numbers for each task were collection through observation of less that ten build associates. Variation may also exist in the number of motions used between build associates.

Validation

Ideally to validate the ergonomic scorecards, one would like to quantify the number of ergonomic injuries associated with building particular systems. Then compare that to the ergonomic scores given to each system. This isn't possible currently at Dell, because build associates do not build just one single system type. In addition, the type of systems each builder receives in their work area is random. These two issues make it difficult to tie ergonomic injuries to a particular system.

For these reasons the ergonomic scorecards were validated by the build associate survey. The builders' system preferences were compared with the ergonomic scores determined by the design scorecards. The systems the builders liked to build received better ergonomic scores than those they didn't like to build. The scores generated by the ergonomic scorecards correlated to the survey results.

Implementation

Implementation of the guidelines and scorecards is being carried out through the support of EHS. The product engineers with the Operations organization have been identified as the owner's of this effort on the processing side. The ergonomics engineer within the PG group who is responsible for the ergonomics of Dell's products from a consumer's point-of-view as been identified as the appropriate owner from the product design side. EHS working collaboratively with these individuals have the task of supporting the use of the design guidelines and scorecards aimed at improving the ergonomics on the factory floor.

Support across both the Operations and Product Group organizations is needed for this project to succeed. A strong commitment from executive and middle management is critical. A shift to further incorporate safety as a priority in the decision making processes needs to occur. This can be accomplished through a combination of efforts. These efforts may include creating awareness, enforcing ergonomics through management, and changing individual metrics.

CHAPTER 6: RECOMMENDATIONS

As a result of this ergonomics project, four main recommendations developed. They are described in detail below.

Engineers "Build for a Day"

The first recommendation is one that can be easily implemented. The product and process design engineers need to gain a true awareness of what is like to work on the factory floor. They need to, simply put, experience the job first-hand. I propose that all design engineers spend time one the factory floor observing build associates in action and work as build associates for a day. When I initially suggested this to some of the product design engineers, I received strong resistance. They replied, "In the last design, I built forty systems in the lab." To this, I acknowledged that, "yes that gives you an understanding of building in a lab setting, but do you appreciate and understand the experience on the floor? Do you know what it is like to build multiple systems an hour while standing?"

With an appreciation of the product and process designers' internal customer, the associates, it will be easier to incorporate the ergonomic needs of associates in the initial design. Beginning to create further awareness by complementing the initial ergonomics classes with a design engineer "build for a day" or even an hour will help bring ergonomics to a higher priority level in the design stages of Dell's new products and processes.

Focus on the Largest Ergonomic Opportunities

As a result of the ergonomic injury analysis, the largest opportunities for ergonomic improvement were identified. The specified actions causing a majority of the ergonomic issues were building, lifting, pushing, and pulling. The ability to influence these behaviors on the factory floor varies in difficulty. It is recommended that the easier issues be addressed first.

Lifting – This issue can be addressed by compliance with factory policies. The challenge of lift prevention is that lifting an item is much quicker than going to get a cart or asking for assistance. In addition in some areas, carts are very difficult to use due to the factory layout. There often are narrow aisles and isn't a lot of storage space for carts on the factory due to extremely high square-foot utilization. The metrics the associates are measured by are speed and quality. This provides associates with an incentive to lift. Unfortunately, these actions are causing many injuries. Only with a strict factory policy on lifting and serious consequences when policies are not followed will address the lifting issue and reduce the high number of lifting injuries.

Pushing & Pulling – This issue of pulling and pushing must be addressed with the new design of factory processes. Most of the injuries associated with pushing and pulling have to do with a mismatch in heights and reach distances. A shorter associate is getting injured due to strain developed when reaching for a system or tote across their workstation. The taller associates are stooping down when pushing or pulling a system or tote, also causing injury. There are no simple fixes to this problem, because the heights and geometries of the work stations are currently fixed. There are possible patch type solutions, such as platforms or automated pushing and pulling equipment. The only true solution to the pushing and pulling problem is to have adjustable work stations that can be adjusted to the associate working in them. One way to implement this in the current factory layout more cost effectively, is to have designated cells or lines set for different height workers. Adjust a few work cells for the shorter and taller associates.

Building – Targeted by future system designs and factory processes, building issues are a big problem that can only be addressed by getting involved early in the design process. Of the three largest contributors to ergonomic injuries, this is the most difficult to prevent because there are so many factors related to the assembly process. If implemented successfully, the ergonomic design guidelines and scorecard will help reduce the occurrence of ergonomic injuries caused by job tasks performed in the build area. Multiple groups will need to work together to improve the ergonomic issues associated with the build process.

Act on Input from the Associates

Employees must be involved with efforts to improve workplace safety. Benefits of worker involvement include:

- Enhanced worker motivation and job satisfaction
- Added problem solving capabilities
- Greater acceptance of change
- Greater knowledge of the workplace and organization

(Cohen, 8)

In order to successfully reduce the number of ergonomic injuries in Dell's factories, factory associates need to get more involved in safety. Ways to foster involvement and maintain involvement include continuing to have employee surveys, awarding and acknowledging those who contribute, and sharing problem solutions. Finally, genuinely listen to ideas and take the time to explain why some ideas cannot be implemented. Through the survey, many of the build associates communicated their understanding of the business. Educating them on the business operations is in Dell's best interest. Working together, employees at Dell are developing safety improvements that are "wins" for both employees and the business.

On a side note, the survey participation from Nashville was remarkable and it is indicative of a culture that values their ideas. The associates wouldn't have spent the time filling out the survey, if they didn't think their ideas were going to be heard. Foster a culture which leads to similar participation at all Dell sites will help in the safety improvement efforts.

Visible Executive and Middle Management Support is Critical

Improving the safety culture at Dell will not be successful without visible and consistent executive and middle management support.

> "Occupational safety and health literature stresses management commitment as a key and perhaps controlling factor in determining whether any worksite hazard control effort will be successful."

(Cohen, 6)

This idea is extremely critical in Dell's strong metric driven organization. Without a strong commitment to safety across all functions, safety improvements at Dell will be overlooked in an effort to meet individual metrics. With a growing strong commitment to safety amongst Dell's executive management team, safety is improving at great rates. With continued support and growing middle management support, the safety in Dell's factories will continue to improve and strengthen as an integral part of Dell's culture.

CONCLUSION

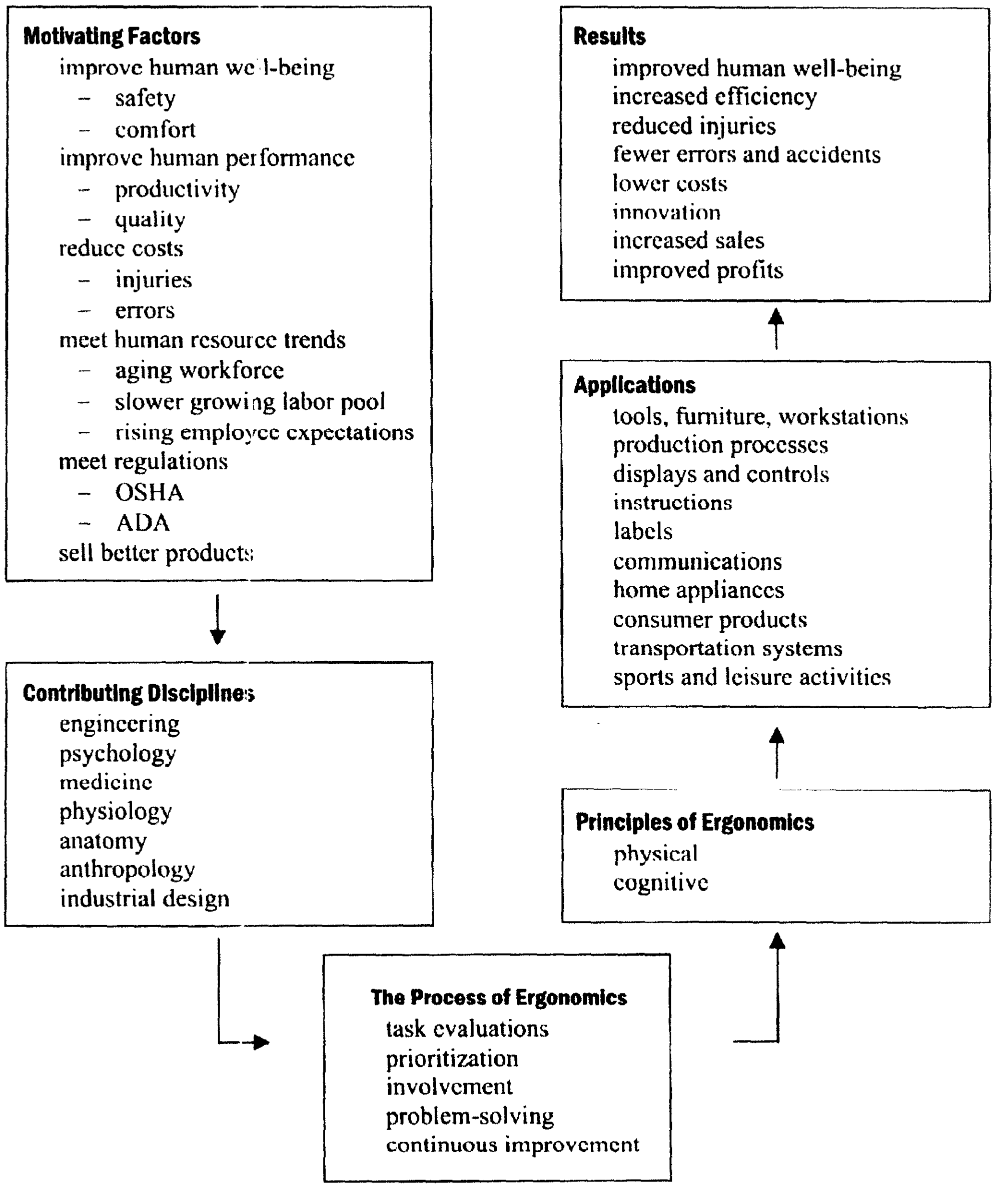
The project strategy selected to influence ergonomic decisions was a proactive approach that included creating awareness, demonstrating the impact of ergonomics through analysis, identifying the greatest opportunities for improvement, developing design tools to evaluate ergonomics, and facilitating implementation of the project.

The project successfully quantified the financial impact of ergonomics to Dell, prioritized the ergonomics injuries by area and casual actions, and developed comprehensive product and process design scorecards and guidelines. The scorecards provide product design and process engineers with tools to evaluate the ergonomic impact of the decisions that they make.

The risk of ergonomic injuries in a repetitive manufacturing environment is significant. It is possible to develop tools to measure ergonomic impact on the employee and the business. Through creating ergonomic awareness and using these tools, decisions can be made on the factory floor and in the design process that have the potential to reduce ergonomic risk factors and provide cost savings to Dell.

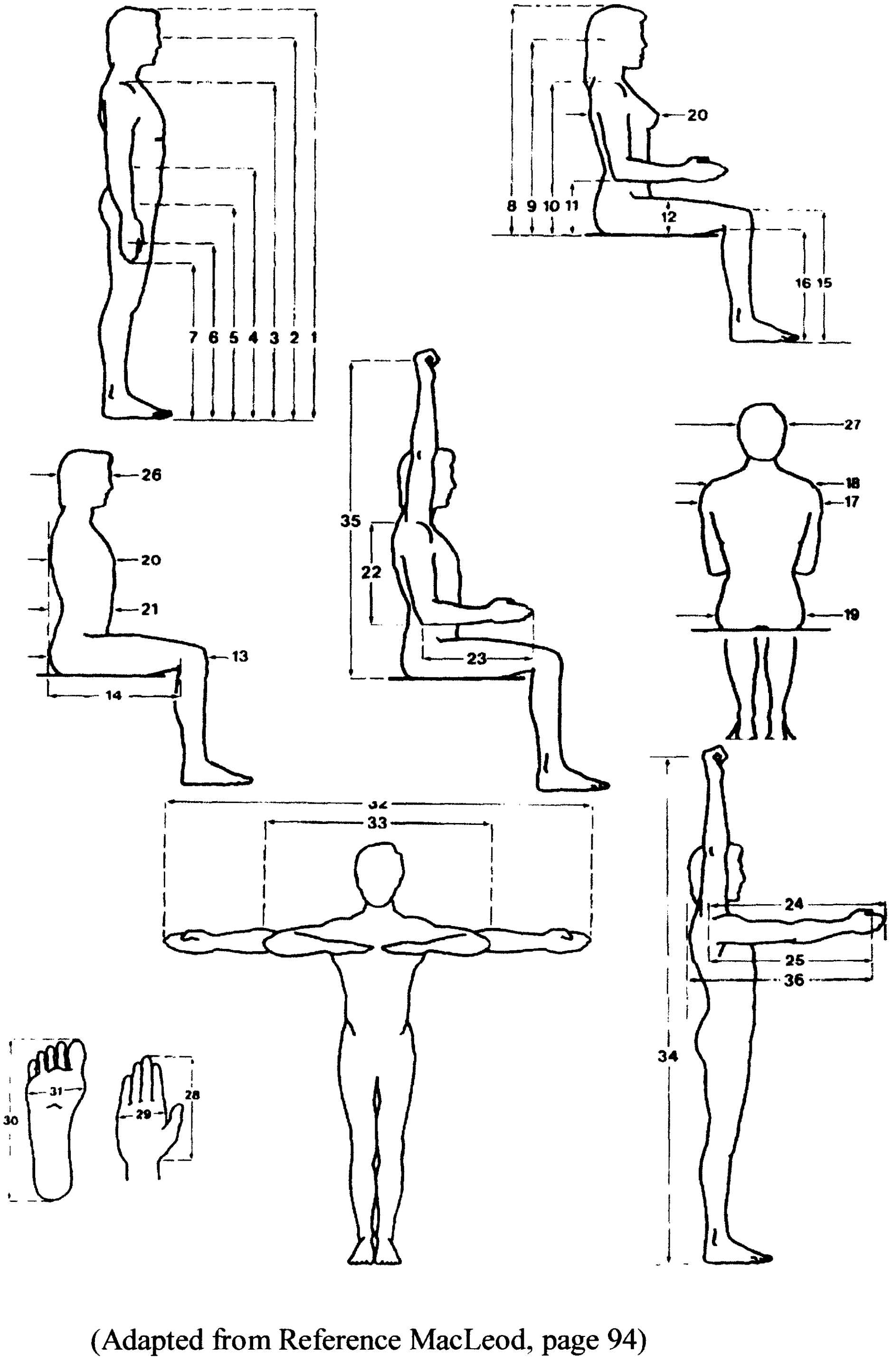
LIST OF APPENDICES

APPENDIX 1: The Scope of Ergonomics



(Adapted from Reference MacLeod, page 7)

APPENDIX 2: Common Anthropometric Measurements



(Adapted from Reference MacLeod, page 94)

APPENDIX 3: Anthropometry Table for U.S. Adults

Anthropometry Table
U.S. Adults (Inches)

Measures	Males				Females			
	5th	50th	95th	1 S.D.	5th	50th	95th	1 S.D.
1. Stature	64.6	69.1	73.6	2.8	59.8	64.0	68.1	2.5
2. Eye Height	62.8	67.3	71.9	2.8	55.9	60.0	64.2	2.5
3. Shoulder Height	52.4	56.7	61.0	2.6	48.2	52.2	56.1	2.4
4. Elbow Height	40.2	43.5	46.9	2.1	37.2	40.2	43.1	1.9
5. Hip Height	32.9	36.0	39.2	2.0	29.9	32.9	35.8	1.8
6. Knuckle Height	27.6	30.1	32.7	1.6	26.4	28.7	31.1	1.5
7. Fingertip Height	23.4	26.0	28.5	1.5	22.2	24.8	27.4	1.6
8. Sitting Height	33.7	36.0	38.4	1.4	31.5	33.9	36.2	1.4
9. Sitting Eye Height	29.1	31.5	33.9	1.4	27.2	29.5	31.9	1.4
10. Sitting Shoulder Height	21.5	23.6	25.8	1.3	20.1	22.2	24.4	1.3
11. Sitting Elbow Height	7.7	9.6	11.6	1.2	7.3	9.3	11.2	1.1
12. Thigh Thickness	5.3	6.3	7.3	0.6	4.9	6.1	7.3	0.7
13. Tailbone-Knee Length	21.7	23.6	25.6	1.2	20.7	22.6	24.6	1.2
14. Tailbone-Popliteal Length	17.5	19.7	21.9	1.3	17.3	19.3	21.3	1.2
15. Knee Height	19.5	21.7	23.8	1.3	18.1	19.9	21.7	1.1
16. Popliteal height	15.6	17.5	19.5	1.1	14.2	15.9	17.7	1.1
17. Shoulder Breadth (bideltoid)	16.7	18.5	20.3	1.1	14.2	15.7	17.3	1.0
18. Shoulder Breadth (biacromial)	14.4	15.7	17.1	0.8	13.0	14.2	15.4	0.7
19. Hip Breadth	12.2	14.2	16.1	1.2	12.2	14.8	17.3	1.5
20. Chest (Bust) Depth	8.7	10.0	11.4	0.9	8.3	10.0	11.8	1.1
21. Abdominal Depth	8.7	10.8	13.0	1.3	8.3	10.2	12.2	1.2
22. Shoulder-Elbow Length	13.0	14.4	15.7	0.8	12.0	13.2	14.4	0.7
23. Elbow-Fingertip Length	17.5	18.9	20.3	0.8	15.7	17.1	18.5	0.8
24. Upper Limb Length	28.7	31.1	33.5	1.4	25.8	28.1	30.5	1.4
25. Shoulder-Grip Length	24.2	26.4	28.5	1.3	22.0	24.0	26.0	1.2
26. Head Length	7.1	7.7	8.3	0.3	6.5	7.1	7.7	0.3
27. Head Breadth	5.7	6.1	6.5	0.2	5.3	5.7	6.1	0.2
28. Hand Length	6.9	7.5	8.1	0.4	6.3	6.9	7.5	0.4
29. Hand Breadth	3.1	3.5	3.9	0.2	2.6	3.0	3.3	0.2
30. Foot Length	9.4	10.4	11.4	0.6	8.7	9.4	10.2	0.5
31. Foot Breadth	3.5	3.9	4.3	0.2	3.1	3.5	3.9	0.2
32. Span	65.7	71.3	76.8	3.3	59.3	64.0	68.7	2.9
33. Elbow Span	34.4	37.6	40.7	1.9	31.1	33.9	36.6	1.7
34. Vertical Grip Reach (Standing)	76.8	81.9	87.0	3.1	71.1	75.8	80.5	2.9
35. Vertical Grip Reach (Sitting)	45.5	49.4	53.3	2.4	42.1	45.7	49.2	2.2
36. Forward Grip Reach	28.5	30.9	33.3	1.4	25.8	28.0	30.1	1.3
37. Body Weight *(in pounds)*	121.0	171.6	224.4	30.8	90.2	143.0	195.8	33.0

(Adapted from Reference MacLeod, page 95)

APPENDIX 4: Anthropometry Table for Japanese Adults

Anthropometry Tables
Japanese Adults (Millimeters)

	Males				Females			
Measures	**5th**	**50th**	**95th**	**1 S.D.**	**5th**	**50th**	**95th**	**1 S.D.**
1. Stature	1560	1655	1750	58	1450	1530	1610	48
2. Eye Height	1445	1540	1635	57	1350	1425	1500	47
3. Shoulder Height	1250	1340	1430	54	1075	1145	1215	44
4. Elbow Height	965	1035	1105	43	895	955	1015	36
5. Hip Height	765	830	895	41	700	755	810	33
6. Knuckle Height	675	740	805	40	650	705	760	33
7. Fingertip Height	565	630	695	38	540	600	660	35
8. Sitting Height	850	900	950	31	800	845	890	28
9. Sitting Eye Height	735	785	835	31	690	735	780	28
10. Sitting Shoulder Height	545	590	635	28	510	555	600	26
11. Sitting Elbow Height	220	260	300	23	215	250	285	20
12. Thigh Thickness	110	135	160	14	105	130	155	14
13. Tailbone-Knee Length	500	550	600	29	485	530	575	26
14. Tailbone-Popliteal Length	410	470	510	31	405	450	495	26
15. Knee Height	450	490	530	23	420	450	480	18
16. Popliteal height	360	400	440	24	325	360	395	21
17. Shoulder Breadth (bideltoid)	405	440	475	22	365	395	425	18
18. Shoulder Breadth (biacromial)	350	380	410	18	315	340	365	15
19. Hip Breadth	280	305	330	14	270	305	340	20
20. Chest (Bust) Depth	180	205	230	16	175	205	235	18
21. Abdominal Depth	185	220	255	22	170	205	240	20
22. Shoulder-Elbow Length	295	330	365	21	270	300	330	17
23. Elbow-Fingertip Length	405	440	475	20	370	400	430	17
24. Upper Limb Length	665	715	765	29	605	645	685	25
25. Shoulder-Grip Length	565	610	655	26	515	550	585	22
26. Head Length	170	185	200	8	160	170	180	7
27. Head Breadth	145	155	165	7	140	150	160	6
28. Hand Length	165	180	195	10	150	165	180	9
29. Hand Breadth	75	85	95	6	65	75	85	5
30. Foot Length	230	245	260	10	210	225	240	9
31. Foot Breadth	95	105	115	5	90	95	100	4
32. Span	1540	1655	1770	70	1395	1485	1575	56
33. Elbow Span	790	870	950	48	715	780	845	41
34. Vertical Grip Reach (Standing)	1805	1940	2075	83	1680	1795	1910	69
35. Vertical Grip Reach (Sitting)	1105	1185	1265	49	1030	1095	1160	41
36. Forward Grip Reach	630	690	750	37	570	620	670	31
37. Body Weight *(in kilograms)*	41	60	74	9	40	51	63	7

(Adapted from Reference MacLeod, page 97)

APPENDIX 5: Anthropometry Table for Brazilian Industrial Workers

Anthropometry Tables
Brazilian Industrial Workers (Millimeters)

Measures	Males			
	5th	50th	95th	1 S.D.
1. Stature	1595	1700	1810	66
2. Eye Height	1490	1595	1700	66
3. Shoulder Height	1315	1410	1510	60
4. Elbow Height	965	1045	1120	49
5. Hip Height	800	880	960	47
6. Knuckle Height	655	720	785	40
7. Fingertip Height	565	625	690	37
8. Sitting Height	825	880	940	35
9. Sitting Eye Height	720	775	830	34
10. Sitting Shoulder Height	550	595	645	29
11. Sitting Elbow Height	185	230	275	28
12. Thigh Thickness	120	150	180	16
13. Tailbone-Knee Length	550	595	650	30
14. Tailbone-Popliteal Length	435	480	530	29
15. Knee Height	490	530	575	27
16. Popliteal height	390	425	465	24
17. Shoulder Breadth (bideltoid)	400	445	490	27
18. Shoulder Breadth (biacromial)	355	385	415	19
19. Hip Breadth	305	340	385	25
20. Chest Depth	205	235	275	22
21. Abdominal Depth	220	245	305	33
22. Shoulder-Elbow Length	335	365	405	21
23. Elbow-Fingertip Length	440	475	510	22
24. Upper Limb Length	725	785	850	38
25. Shoulder-Grip Length	615	670	725	34
26. Head Length	175	190	205	8
27. Head Breadth	140	150	160	6
28. Hand Length	170	185	200	9
29. Hand Breadth	75	85	95	5
30. Foot Length	240	260	280	12
31. Foot Breadth	95	100	110	5
32. Span	1625	1755	1885	78
33. Elbow Span	855	925	995	44
34. Vertical Grip Reach (Standing)	1895	2020	2145	75
35. Vertical Grip Reach (Sitting)	1130	1220	1310	56
36. Forward Grip Reach	710	765	820	32
37. Body Weight *(in kilograms)*	52	66	86	11

(Adapted from Reference MacLeod, page 99)

APPENDIX 6: Build Associate Survey – Page 1

Build Survey

This is an anonymous survey. Your answers will not be linked back to you in any way. This survey is for research purposes.

Please complete the following 13 questions.

1. How long have you been working at Dell?

☐ less than 6 months
☐ 6 months – 1 year
☐ 1 – 2 years
☐ 2 – 4 years
☐ 4 – 6 years
☐ more than 6 years

2. How long have you been building computers at Dell?

☐ less than 6 months
☐ 6 months – 1 year
☐ 1 – 2 years
☐ 2 – 4 years
☐ 4 – 6 years
☐ more than 6 years

3. What line do you currently build on?

☐ EG1 Line 1
☐ EG1 Line 2
☐ EG1 Line 3
☐ EG1 Line 4
☐ EG1 Line 5

4. Check ALL the systems you have built during your time at Dell.

☐ System A
☐ System B
☐ System C
☐ System D
☐ System F
☐ System G
☐ System H
☐ System I
☐ System J
☐ System K
☐ System L
☐ System M

APPENDIX 7: Build Associate Survey – Page 2

5. Of the systems you have built, which system do you like to build the BEST?

☐System A
☐System B
☐System C
☐System D
☐System F
☐System G
☐System H
☐System I
☐System J
☐System K
☐System L
☐System M

6. Why do you like this system the BEST? Check all that apply.

☐It has few components to install
☐Its components are in locations that are easy to install
☐Its components require little effort to get into position
☐I have built many of them
☐I don't have to use the torque driver
☐It doesn't have any screws
☐Its chassis is easy to open
☐Its chassis is easy to close
☐I don't have to prep the motherboard
☐I don't have to lift the system
☐Other________________________
☐Other________________________

APPENDIX 8: Build Associate Survey – Page 3

7. Of the systems you have built, which system do you like to build the LEAST?

☐ System A
☐ System B
☐ System C
☐ System D
☐ System F
☐ System G
☐ System H
☐ System I
☐ System J
☐ System K
☐ System L
☐ System M

8. Why do you like this system the LEAST? Check all that apply.

☐ It has many components to install
☐ Its components are in locations that are difficult to install
☐ Its components require much effort to get into position
☐ It is a new system for me
☐ I have to use the torque driver
☐ It has screws
☐ Its chassis is difficult to open
☐ Its chassis is difficult to close
☐ I have to prep the motherboard
☐ I have to lift the system
☐ It causes me discomfort
☐ Other________________________
☐ Other________________________

APPENDIX 9: Build Associate Survey – Page 4

9. Which ONE of the following components is EASIEST to install?

☐Processor (CPU)
☐Heat Sink
☐DIMM
☐Cables to Motherboard (MB)
☐Hard Disk Drive (HDD)
☐Floppy Drive
☐Optical Drive (CD, DVD, & CD/RW)
☐Data Cables to Drives
☐Power Cables to Drives
☐Fan
☐Speaker
☐Option Cards
☐Other______________

10. Which ONE of the following components is MOST DIFFICULT to install?

☐Processor (CPU)
☐Heat Sink
☐DIMM
☐Cables to Motherboard (MB)
☐Hard Disk Drive (HDD)
☐Floppy Drive
☐Optical Drive (CD, DVD, & CD/RW)
☐Data Cables to Drives
☐Power Cables to Drives
☐Fan
☐Speaker
☐Option Cards
☐Other______________

11. What slows you down the most in build?

12. What could be done to allow you to build more easily?

13. Do you have any other suggestions/comments about your job?

You have completed this survey.
Thank you so much for your time and input!

APPENDIX 10: Ergonomic Design Guidelines – Force

Force					
Grip Action	lbs			*Ergonomic Risk Level*	**Ergo Score**
x = force measured to complete task	x	>=	8.6	High	▨
	8.6	>x>=	4.3	Moderate	**2.5**
	4.3	>	x	Low	**0**
Pinch Action	lbs			*Ergonomic Risk Level*	**Ergo Score**
x = force measured to complete task	x	>=	3.2	High	▨
	3.2	>x>=	1.6	Moderate	**2.5**
	1.6	>	x	Low	**0**
One Finger Push	lbs			*Ergonomic Risk Level*	**Ergo Score**
x = force measured to complete task	x	>=	5.8	High	▨
	5.8	>x>=	3.0	Moderate	**2.5**
	3.0	>	x	Low	**0**
Multiple Finger Push	lbs			*Ergonomic Risk Level*	**Ergo Score**
x = force measured to complete task	x	>=	9.0	High	▨
	9.0	>x>=	5.0	Moderate	**2.5**
	5.0	>	x	Low	**0**

Source:
* DF Ergo

* DF Ergo

* DTI Strength Study Phase 1

* DTI Strength Study Phase 2

APPENDIX 11: Ergonomic Design Guidelines – Motion Repetition

Repetition				Source: ANSI Z-356 draft
Shoulder Flexion & Abduction	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	x>150		High	[illegible]
	150>x>90		Moderate	**2.5**
	90>x		**Low**	**0**
Wrist Movement	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	**x>1800**		**High**	[illegible]
	1800>x>900		**Moderate**	**2.5**
	900>x		Low	**0**
Hand Interface - Grasp & Pinch	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	x>1800		High	[illegible]
	1800>x>900		Moderate	**2.5**
	900>x		Low	**0**
Fingers - **Key Strokes**	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	x>18000		High	[illegible]
	18000>x>15000		Moderate	**2.5**
	15000>x		Low	**0**
Fingers - Single Action	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	x>2000		High	[illegible]
	2000>x>1000		Moderate	**2.5**
	1000>x		Low	**0**
Neck Movement & Rotation	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	x>180		High	[illegible]
	180>x>120		Moderate	**2.5**
	120>x		Low	**0**
Back - Bending, Lifting, Twisting & Lowering	**# of motions per hour**		*Ergonomic Risk Level*	**Ergo Score**
x = **# motions per hour**	x>120		High	[illegible]
	120>x>30		Moderate	**2.5**
	30>x		Low	**0**

APPENDIX 12: Ergonomic Design Guidelines – Posture

Posture						Source:
Bench Height		**inches**		*Ergonomic Risk Level*	**Ergo Score**	
x=fixed bench height (inches)	x	>=	38	High	▨	NIOSH & Semi
	38	>x>=	35	Moderate	**2.5**	
	35	>	x	High	▨	
		Adjustable		Low	**0**	
Chassis Wall Height		**inches**		*Ergonomic Risk Level*	**Ergo Score**	
x=height (inches)	x	>=	5	High	▨	
	5	>x>=	2	Moderate	**2.5**	
	2	>	x	Low	**0**	
Component Spacing		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
	4	sides with < 1 inch spacing		High	▨	
	3	sides with < 1 inch spacing			**3.75**	
	2	sides with < 1 inch spacing		Moderate	**2.5**	
	1	sides with < 1 inch spacing			**1.25**	
	0	**sides with < 1 inch spacing**		Low	**0**	
Component Location		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
		Mounted on chassis wall		High	▨	
		Horizontal Insertion		High	▨	
		Located < 1.0 from wall		**Moderate**	**3**	
System Weight		**lbs**		*Ergonomic Risk Level*	**Ergo Score**	
x=weight (lbs)	x	>=	22	High	▨	DTI Strength Phase 2
	22	>x>=	11	Moderate	**2.5**	
	11	>	x	Low	**0**	
Tote Location		**inches**		*Ergonomic Risk Level*	**Ergo Score**	
x=maximum reach (inches)	x	>=	22	High	▨	Semi
	22	>x>=	16	Moderate	**2.5**	
	16	>	x	Low	**0**	
Tote Handling		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
		Lift Tote		High	▨	
		Lower Tote		High	▨	
		Automated: Push Button		Low	**0**	
Keyboard Location		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
x=fixed keyboard height (inches)	x	>=	50	High	▨	Semi
	50	>x>=	37	Moderate	**2.5**	
	37	>	x	High	▨	
		Adjustable		Low	**0**	
Trash Location		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
		Requires bending and reaching		High	▨	
		Requires bending or reaching		Moderate	**2.5**	
		Requires no bending or reaching		Low	**0**	
Power Driver Location		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
x=fixed driver height (inches)	x	>=	50	High	▨	Semi
	50	>x>=	37	Moderate	**2.5**	
	37	>	x	High	▨	
		Adjustable		Low	**0**	
Scanner Location		**Input**		*Ergonomic Risk Level*	**Ergo Score**	
x=fixed scanner height (inches)	x	>=	50	High	▨	Semi
	50	>x>=	37	Moderate	**2.5**	
	37	>	x	High	▨	
		Adjustable		Low	**0**	

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