ABSTRACT

A CONCEPTUAL FRAMEWORK OF COST/BENEFIT JUSTIFICATION FOR ERGONOMIC PROJECTS TO REDUCE MUSCULOSKELETAL DISORDERS IN THE WORKPLACE

by
Nitipong Boon-long

A framework for justifying ergonomic projects to the overall cost savings is developed which estimates the extent of musculoskeletal disorders (MSDs) exposures to a specific industry. A cost structure is developed to estimate the investment needed for an ergonomics program and the costs related to MSDs problems including workers' compensation costs, work-related costs, and labor turnover costs. Data was adopted from sources including Bureau of Labor Statistics (BLS), the Healthcare Cost and Utilization Project (HCUP-3), and estimates suggested in OSHA's former Ergonomics Standard. Top fifteen manufacturing industries with the highest MSDs rates were selected to apply the framework. Results showed that the overall cost savings among the fifteen selected industries come from ergonomics activities addressing the problem of overexertion (58%), bodily reaction (15%), and repetitive motion (27%). The study makes it possible to identify the proportion of exposure types that contribute to the overall costs of MSDs problems, so that managers can prioritize ergonomic analysis and control activities appropriately. Furthermore, based on the literature review, this is the first study to investigate the feasibility of using *Real Options* method to quantify ergonomic investment as well as an attempt to identify different types of real options in ergonomics program. Results showed that the value of ergonomics program could increase up to 2.43 times of the original value when real options are included.

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by
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A CONCEPTUAL FRAMEWORK OF COST/BENEFIT JUSTIFICATION FOR ERGONOMIC PROJECTS TO REDUCE MUSCULOSKELETAL DISORDERS IN THE WORKPLACE

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CHAPTER 1

INTRODUCTION

1.1 Background

Companies have found that occupational health and safety costs have increased dramatically during the past ten years due to an increase of injuries and illnesses in the work place *(Brown, 1996; Melhorn, 1994a; Murphy, et al., 1996; Hashemi, 1998; Silverstein et al., 1997; Mital, 1997).* The direct increase of company cost is the workers' compensation cost *(Alexis, 1989; Joines and Ayoub, 1995; Gilad, 1995; Bonzani et al., 1997).* The Occupational Safety and Health Administration (OSHA), Bureau of Labor Statistics (BLS), the National Institute for Occupational Safety and Health (NIOSH), and experts have identified that musculoskeletal disorders (MSDs) is one of the fastest growing work-related disorders in the country *(Brogmus, Sorock and Webster, 1996; Stobe, 1996; Hagberg, 1992; NIOSH, 1997, BLS Website).*

MSDs represents a set of pathological conditions that impair the normal functions of the soft tissues of the musculoskeletal system, such as tendons, muscles, cartilages, ligaments, and nerves. MSDs arises when the musculoskeletal soft tissues are subjected to repeated physical stress, usually from repetitive movements, static posture, continuous loading on tissue structure, or a combination of those stresses which in turn causes gradually accumulating tissue damage *(Melhorne, 1994a; Rizzo, 1997; Cassvan, 1997).* Such physical stresses that contributed to or cause MSDs are called "risk factors." Therefore, by understanding the potential risk factors of MSDs, methods for preventing or solving such problems can be developed.

The initial symptoms of MSDs may include muscle fatigue, discomfort, and pain. When tissue damage worsens, other symptoms, such as weakness, numbness, or restricted movements, may also appear. Symptoms, such as muscle fatigue or pain at work that disappears during rest, often appear gradually, but become more severe as exposure continues. If the worker continues to be exposed to risk factors, symptoms may worsen to a point that affects the ability to perform the job. In some cases the MSDs can cause substantial impairment and permanent disability *(NIOSH, 1997; Weiss, 1997).*

MSDs have been referred to by other names, such as cumulative trauma disorders (CTD), repetitive strain injuries (RSI), and occupational overuse syndrome *(Melhorne, 1994a).* However, MSDs do not include musculoskeletal injuries that are caused by accidents. Instead, MSDs reflects tissue damage and function loss that occur over time from prolonged or frequent exposure to risk factors. Examples of MSDs injuries and illnesses conditions are carpal tunnel syndrome (CTS), sprain and strain, tendonitis, trigger finger, and low back pain.

The treatments of MSDs include rest, alleviation of pain, elimination of stress, relaxation, and preservation of elasticity, contractility, and strength. Injection is another treatment option where a mix of lidocaine and steroids is used to treat initial inflammatory symptoms *(Cassuan, Weiss, and Mullers, 1997).* Other approaches include physical therapy, ultrasound, heat, and surgery.

Many researchers, medical doctors, industrial engineers, human factor engineers, and ergonomists have been working to identify the best solutions to prevent, control, and solve such problems *(Silverstein, 1986; Melhorne, 1994b; Gilad, 1995; Kemmlert, 1995, McCann, 1996; Terrence, 1996).* Researchers study ways to predict, assess, detect and quantify such risk factors by using various techniques including fuzzy modeling *(McCauley and Badiru, 1996)*, linear regression *(McCauley, 1997)*, neural network model to identify CTD *(Killough, 1995)*, risk factor index model *(James et, al., 1997)*, object-oriented risk assessment *(Moyniham, 1995)* or an stress strength interference model for predicting CTD probabilities *(Miller and Freivalds, 1995)* but no evidence has been found to be conclusive. Examples of preventive measures range from detailed task analyses *(Gilad, 1995)* and ergonomics training *(Rizzo, 1997; Christine, 1994)*, to a company wide program such as a participative ergonomics program *(Drury, 1994 and 1997; Kuorinka, 1997; Jones, 1997; Vincent, 1998; Maciel, 1998; Moore and Garg, 1997a, 1997b, and 1998)*.

Ergonomics approach, such as a review of health/safety data, a work-site survey, and corrective actions, are recommended by experts *(Cohen, 1997)*. The use of an ergonomic framework has proved to be effective in reducing the problems associated with work-related MSDs *(Silverstein, 1986; Pravikoff, Joyce and Simonowitz, 1994; Koh, 1995; Kohn, 1996; Terrence, 1996; Paxton, 1997)*. Nevertheless, MSDs still occurs frequently in the work place. Thus, OSHA has begun to set an ergonomics program standard to prevent or eliminate such injuries and illnesses *(OSHA CFR1910.900, 1999)*.

The Occupational Safety and Health Administration (OSHA) former ergonomics standard hoped to reduce injuries and illnesses resulting from work-related MSDs (WMSDs), but critics are still skeptical about such program *(Attaran, 1996)*. Debates continue about OSHA's regulation program because scientific evidence that links injuries and illness to the workplace is still limited *(Higgs and Young 1996; NIOSH, 1997)*.

Companies are also concerned about the increased cost impact that can occur from ergonomic activities to meet the new standard *(Hawesworth, 1995)*. Even though workers' compensation reductions and productivity improvements have been identified as gained benefits through ergonomic interventions at companies such as American Express *(Larson, 1996)*, IBM *(Helander and Burri, 1995)*, Intel *(Gardner, 1996)*, paper manufacturing *(Macleod and Morris, 1996)*, and Chrysler *(Witt et. al., 1996)*, companies often avoid ergonomic intervention because of the perceived high costs to the company, legal difficulties, and company politics *(Attaran, 1996)*. As a consequence, the problem of justifying ergonomic solutions aimed at avoiding health and safety problems before occurring has come to the forefront for decision makers in eliminating the root cause of these problems at the shop floor *(Riel and Imbeau, 1997; Hansen and Kysar, 1997)*.

Companies need to follow OSHA former ergonomics standards but at the same time, ergonomic intervention strategies are difficult to be justified in quantitative terms. Many researchers have investigated methods in preventing ergonomics problems *(Bragg, 1996)*; presently few studies on economic concerns of ergonomic interventions have been performed. The reason for such limited number of studies is the lack of understanding of the relationships between ergonomic interventions and their associated benefits *(Higgs and Young, 1996)*. With such limited knowledge in the cause and effects of ergonomic projects aiming to prevent MSDs, the cost justification of ergonomic projects has remained inconclusive.

In addition, researchers do not have enough information to quantify the amount of dose changes (risk factors) that can directly reduce MSDs injuries. Researchers need to conduct experiments to compare one group of workers which has reduced risk factors to another which has not (a control group). Findings of such case controls are rare. Such research difficulty in determining dose-response relationship is one of the weak points of OSHA's case to convince industry to adopt its former ergonomics standard. One reason may be that MSDs often develop over time, which makes it difficult to connect/measure the dose-response relationships. Therefore, benefits generated as a result of ergonomic interventions and their effectiveness to reduce work-related MSDs are difficult to estimate.

Furthermore, there is a need to view ergonomic projects as investment instead of as a cost-generated function. Some ergonomic projects are not widely implemented due to their perceived low investment returns. Finally, the complexity of ergonomic project valuation requires a method to value ergonomic investments that involve knowledge of an uncertain future outcome. The common tool for valuing investment project such as the discounted cash flow (DCF) method could be inappropriate when the future outcome of such projects is not certain *(Trigiorgis, 1993; Tiesburg, 1996).* An alternative project valuation tool called "Real options" can provide additional information about the value of a project in terms of the time to implement (defer or speedup), and decision of investment (to expand, to contract, to switch, or to abandon). When sequential projects are interrelated and management has the flexibility to alter or modify the planned project based on more knowledge about future uncertainties, measuring the project's value using DCF can underestimate the total value of a project.

Real options have been applied to quantify the value of various investment projects such as oil exploration, research and development (R&D), flexible manufacturing, and telemedicine systems. The real options analogy sees R&D projects as an option to acquire revenue streams from future production and commercialization phase. Therefore, the value of R&D project is derived based on the project itself and the option to acquire future revenue by further invest in the production and commercialization phase. The method to quantify such an option is similar to the method used in quantifying a call option on stock where the owner of a call option has the rights without obligation to buy a stock at a fixed priced on or before a given date. Ergonomics program consisted of series of investment outlays that are dependent upon each other and management has the ability to make changes to the planned project. It would be beneficial to investigate the feasibility of using *real options* as additional tool to quantify the value of ergonomic projects so that additional information related to the time and decisions of implementation can be presented.

1.2 Current Practice

The approaches that are commonly taken in justifying ergonomic projects can be grouped into three categories: cost-benefit analyses, cost-effective analyses and discounted cash flow methods. A comparison between the project's costs and benefits/savings gained from ergonomic projects can be used for a cost-benefit analysis. Such a comparison can be shown by a simple calculation in the form of the value/cost ratio. The decision criteria is based on the concept that the benefits should exceed the cost. The method is suggested as an effective way to value low-cost ergonomic solutions (*Corlette, 1988; Bruce Lyon, 1997; Lanoie and Tavenas, 1997*). However, some disadvantages could arise from the cost-benefit analysis method because it requires accurate cost and benefit estimates in order to have a good evaluation *(David Alexander, 1998*). More often however, the estimated benefits are overstated *(Riel and Imbeau, 1997).* Another disadvantage is that the existing costs must be identified, but very difficult, especially for indirect costs. Since the cost and benefit of an ergonomic project is not easily identifiable. A cost-benefit analysis should be used only when the full costs and benefits are measurable *(Riel and Imbeau, 1994b).*

A second method, the cost-effective analysis, is derived from the cost-benefit analysis originated from the evaluation of complex defense and space systems (*Thuesen and Fabrycky, 1993*). Instead of determining the benefit in monetary terms, the reduction in illness and injury cases can be used as an effective measure (*Alexander, 1994*).

In terms of measuring the value of a project, the most acceptable project valuation method is the net present value (NPV) *(Brealey and Myers, 1991; Ross, Westerfield, and Jaffe, 1996; Damodaran, 1997).* This method takes into account on the time value of money, since management is concerned with the value creation that can affect the changes in the company value. In principle, a positive NPV will reflect the future growth of the company. An ergonomic project with positive NPV tends to be more attractive to management. Other justification methods such as the payback period or breakeven analysis are also often used in justifying ergonomic projects (*Oxenburg, 1997; Riel and Imbeau, 1996).*

1.3 Limitations

Cost justification for ergonomic interventions is a difficult task for the health and safety community. In addition, the financial decision makers often perceive ergonomics as a "soft science", an unneeded regulatory requirement, or a cost-prohibitive luxury

(*Lyon, 1997; Attaran, 1996*). The benefits generated from ergonomic projects are also difficult to measure. It is unclear what parameters should be used for quantifying costs and benefits of ergonomic improvements. One major problem of such a cost justification is that a cost model must be available in order to justify an investment in health and safety practices (*Riel and Imbeau, 1995a*).

The data to support ergonomic interventions is often missing and difficult to keep track of. Health and safety related costs are not defined precisely. Accounting systems have not been designed to capture the costs incurred from health and safety problems (*Dahle'n and Wernersson, 1995; Riel and Imbeau, 1996*). The accuracy of the cost estimate is difficult to be achieved. An over-estimated ergonomic benefit is often applied in order to seek management approval (*Lyon, 1997*). These roadblocks and others incite can influence decision makers in the field to invest in low-cost solutions that have short-term implications and often do not solve health and safety problems permanently or even in a significant way (*Riel and Imbaeu, 1995b and 1995c*).

Alexander (1994) suggested that further exploration in utilizing investment techniques instead of a cost/benefit analysis, an allocation of funds, or project ranking, will be beneficial to the safety and health community. On the other hand, there are few studies of health and safety cost modeling aimed at performing economic evaluations of investments for health and safety interventions (*Riel and Imbeau, 1996*). In the past, the traditional economic evaluation such as the DCF method was commonly used. Using the outcome of the DCF method as the criterion for selecting ergonomic projects is often practiced (*Rouse, 1997; Andersson, 1992a and 1992b; Alexander, 1994 and 1998; Lanoie and Tavenas, 1996; Buck, 1998*). Based on the DCF method, the decision to implement ergonomic intervention is viewed as a static approach. It is considered static due to the fact that the method relies mainly on the predicted cash flows generated and the discount rate used in order to assign the value of the project at a static point in time (*Kulatilaka, 1998*).

In addition, studies have suggested that the NPV method can only help to decide whether to invest or not, now or never (*Dixit and Pindyck, 1995; Trigeorgis, 1993; Ross, 1995*). Nevertheless, the linkage for ergonomic improvements through economic evaluation models remains unclear, which makes traditional economic evaluation unreliable. Strategic questions related to the appropriate time that an ergonomic intervention should be implemented, at what expense, and how to monitor and control remains a difficult task. Other strategic questions must be identified such as: Can an ergonomic solution be switched, changed or modified? How much does it cost? and what is the value of the alternatives to make changes when more knowledge of the problems are identified? However, the existing ergonomic justification framework does not help much in making these strategic decisions. Decisions are made mainly on the conclusion reflecting either good or bad.

Ergonomic projects cannot be correctly valued using the DCF method because there are some possibilities for an ergonomic project to be deferred, terminated or switched if the future outcome suggests to do so. The value of such alternatives cannot be correctly measured using the DCF method (*Trigeorgis and Mason, 1987; Kulatilaka, 1993; Teisberg, 1996*). It would be beneficial for the health and safety communities to have an alternative framework that is possible to quantify strategic decisions that are involved in ergonomic investment planning to prevent work-related MSDs problems.

By showing the full value of each ergonomic project, including the value of the ability to defer, to accelerate, to undertake a sequence of investment, as well as the ability to identify optimum timing, a better decision can therefore, be achieved.

1.4 Methodology Overview and Research Objectives

A financial decision support framework is developed to justify ergonomic investments for reducing work-related MSDs. The relationships between ergonomic projects and benefits gained from reducing/eliminating work-related MSDs in financial terms are investigated. A database for estimating MSDs related costs and the investment needed for an ergonomics program to reduce WMSDs for a specific industry according to its standard industrial code (SIC) is developed so that injury cases can be checked by exposure types and the type of injury and illness. According to the categorization by Bureau of Labor Statistics (BLS) exposure types included overexertion, bodily reaction, repetitive motion; and injury/illness types included sprain/strain, back pain, CTS, tendonitis. The database uses data collected from BLS (1993-1997), OSHA (2000), Healthcare Cost and Utilization Project (1993-1996), and research findings to formulate an information system that can determine the potential costs of MSDs as well as the cost to improve working conditions to meet the guidelines of OSHA's former Ergonomics standard (CFR1910.900). The cost to implement ergonomic projects for each SIC follows the structure of OSHA's former ergonomics standard that outlines five elements, namely initialization, basic program, task analysis, ergonomic control, and program evaluation. The estimated benefits of ergonomic projects will be derived from the reduction of workers' compensation costs, work-related costs, and labor turnover costs. The dollar figures used in the database are adjusted to the same year through out the entire study.

Workers' compensation costs are calculated based on medical and indemnity payments that are triggered by the number of MSDs cases. In this study it is assumed that workers' compensation costs will eventually be paid out to the insurance company through the premiums charged *(Everett and Thompson, 1995)*, therefore, workers' compensation costs are determined directly as opposed to using workers' compensation insurance premiums as one of the MSD costs. The medical payment per case is estimated using data collected from the Healthcare Costs Utilization Project (HCUP-3) from 1993 to 1995. The types of injuries and illnesses selected from HCUP-3, which are extracted from the list of Diagnostic Related Groupings (DRG) and Clinical Classification Software (CCS), are those that are candidates for WMSDs. Medical expenses for a selected injury were estimated using an average cost during a five-year time frame or a regression function (when the r-square is significant) that can estimate the medical expenses for each MSDs related illness.

The indemnity payment costs are based on the temporary disability payment (TDP) and the permanent disability payment (PDP). The TDP is estimated using the average days away from work due to the nature of the illness. The average days away from work is derived from BLS data between 1993 and 1997. Then the PDP is estimated from the TDP, by multiplying the TDP by 2.174 (the ratio derived from OSHA's recommended percentage for estimating PDP when TDP is known.

Work-related cost increment due to WMSDs are calculated based on the number of restricted work-activity cases. During the restricted-activity period, workers are assumed to perform activities with performance level below their normal capacity. The study assumes that workers will perform at 1/3 below their normal capacity during the restricted-activity period. Work-related cost is estimated by multiplying the number of restricted-activity cases, the percentage of worker's performance with respect to normal capacity during the restricted-activity period, the average restricted workdays for a given exposure type, and worker's hourly wage.

The labor turnover cost increment due to WMSDs is estimated based on an assumption that workers with loss days over one month may leave their jobs. It directly increases the labor turnover costs if such cases happen. The labor turnover costs are determined by multiplying the number of turnover cases and the average replacement costs per worker.

To apply the proposed approach, the top fifteen industries with high MSDs cases during 1994 – 1998 (BLS website) are selected for this study. Ergonomic investment opportunities are quantified using real-options method so that it can be compared with other financial investment opportunities. Real-options is a methodology used for quantifying investment opportunity *(Myers, 1984; Trigeorgis, 1987, 1991a, 1993b; Kulatilaka, 1993; Dixit and Pyndick, 1995; Teisberg, 1996).* The net present value (NPV) and the real options method are used to determine the value of ergonomic project. Comparisons between the two methods are investigated. The objectives of the study can be summarized as follows:

1. To introduce a conceptual framework of cost/benefit justification for ergonomics program aiming at reducing MSDs in the manufacturing industry. By developing a framework that clearly defines the parameters of MSDs related costs and their relationships that can be used for estimating potential benefits (in terms of cost reductions) as well as estimating investments needed for implementing an ergonomics program to reduce work-related MSDs in the manufacturing industry according to the standard industrial code. With such a structure, a database system is created to provide a mechanism for estimating the costs and benefits that users can use for valuing ergonomic investments.

2. To utilize large-scale data sources, which contain the information related to occupational injuries and illnesses such as MSDs incidence rate, days away from work, medical costs, and elements of ergonomics program. It is anticipated that when such data items are not available, estimates using regression, averages, or expert opinions are adopted in order to provide the information needed for the proposed cost-benefit framework.

3. To investigate the feasibility of using the real options approach as a tool for valuing strategic ergonomic investments as well as an attempt to identify different types of real-options in an ergonomics program. Such method can be used for determining the market value of an ergonomic project that can be compared with other methodologies.

CHAPTER 2

LITERATURE REVIEW

2.1 The Existing Ergonomic Problems

Studies found that MSDs have become a major type of injury/illness in the workplace (*Webster and Snook, 1994*). Occupational diseases affect 15 to 20% of the overall injury/illness, and MSDs account for 56% of those occupational injuries/illnesses (*Melhorn, 1994*). Using government statistics Webster (1994) estimated that the total cost of upper extremity MSDs cases in the United States in 1989 was $563 million of workers' compensation costs. The average cost per case for upper extremity MSDs was $8,070, which was almost twice as much of an average workers' compensation claim ($4,075). The medical cost was approximately one-third of the total cost while indemnity payment for lost wages made up almost two thirds of the total cost. It was concluded from other studies that the direct health care cost of MSDs related problems for the national workforce is over $418 billion, and the indirect cost is estimated to be over $837 billion (*Brady et. al., 1997*).

Data from the Bureau of Labor Statistics in 1996 showed that a total of 626,000 MSDs cases resulted in days away from work *(BLS, 1996)*. The five private industries with the highest number of cases of MSDs accounted for 54,900 cases out of 281,100, or 19.5%. Even though the number of MSDs cases have risen from 23,800 in 1972 to 332,000 cases in 1994, the percentage of MSDs among the overall injury/illness has remained roughly constant, from 62% in 1992 to 64% in 1996.

Among the 281,100 total cases of MSDs in 1996, 203,036 cases, approximately 72 percent, occurred in manufacturing industries. Brogmus *et al.* (1996) documented national trends in work-related upper extremities MSDs by year, occupation, and selected industries, and evaluated some of the recent upward trends. A steady increase in the proportion of MSDs cases was also reported. The main illnesses of MSDs concentrate on the wrist, hand and fingers involving respectively about 31, 12 and 11 days away from work. Almost half of the repetitive trauma disorders are due to carpal tunnel syndrome (CTS), where 48 percent involve an average of over 31 days away from work. *Hashemi et al. (1998)* studied the length of disability (LOD) of upper extremity MSDs problems and found that the LOD had an average of 87 days.

Virtually all cases of MSDs result from stress or strain on workers' wrists due to repetitive movement such as grasping, scanning groceries, typing, or cutting meat or poultry on an assembly line. Another major cause of MSDs is due to overexertion, and awkward posture. The need for controlling injuries and illnesses due to work-related MSDs is obvious. Various studies have been done to address the issue of MSDs prevention, detection, and cause of MSDs *(Bragg, 1996; Faville, 1996; Brown, 1997; Dickerson, 1997)*. *Stobbe (1996)* gave a review of cumulative trauma disorders for upper extremities and the low back from an ergonomic perspective and discussed controlling and preventive approaches for a few situations. The author defined the four primary risk factors: posture, muscular force applied, frequency and duration. Epidemiological data show that the risk of hand and wrist tendonitis in workers who perform highly repetitive and forceful jobs is 29 times greater than in persons who perform jobs that are low in repetitiveness and force *(Armstrong et al. 1987)*.

Higgs (1996) briefly reviewed the diagnostic and treatment of MSDs to the hand and wrist. From the statistical data and research papers one can see that the problem of

MSDs in the workplace is significant. It is important for health and safety professionals, as well as ergonomists, industrial engineers, and industrial hygienists, to pursue methods and tools for assessment of certain jobs with high risk and develop intervention strategies *(Brogmus, Sorock and Webster, 1996)*.

2.2 Ergonomic Solutions for MSDs

Many ergonomic intervention approaches have been developed to reduce and even to prevent them. However, the method to monitor and measure performance of the intervention is not feasible to industrial practices due to the lack of information related to the cause and effect of MSDs. *Silverstein and Stetson (1997)* designed a surveillance system for work-related MSDs based on the specific characteristics of a possible data source. The study was shown that early identification of WMSDs would be beneficial in order to identify and reduce work-related risk factors and provide early treatment where appropriate. The data source consisted of workers' compensation, personal medical benefits, mandated reporting, employer records, self-reports and in-person assessments. With the use of a checklist of risk factors, summary scores for each specific person were compared with persons without symptoms.

Silverstein (1997) also compared the features of two surveillance systems for upper extremity MSDs using a preexisting data source (PDS) versus the use of questionnaires/physical examination (QPE). Later, *Bonzani (1997)* studied factors prolonging disability in work-related MSDs that caused high compensation costs. He proposed a classification system that will assist surgeons in identifying of these factors and presented a treatment model for groups involving MSDs, ergonomic issues and psychosocial issues. Bonzani's studies was shown that the psychosocial is the primary factor prolonging disability.

Pravikov (1994) recommended a framework used in structuring an ergonomic injury prevention program. The basic components of the framework include a systematic evaluation of the job/work site, record keeping and documentation, early recognition, engineering & administrative controls, and training of workers. The framework is an easy reference but a lot more details and economic evaluation need to be included. *McCann (1996)* introduced a preventive program by combining behavioral training and ergonomic design approach to prevent carpal tunnel syndrome (CTS) for computer workers in a controlled environment. She qualitatively compared dependent variables such as posture, hand-wrist position and data entry rates between groups that conducted training versus a baseline group. McCann concluded that the risk of developing CTS was assumed to reduce in the long run when training programs were implemented.

Rizzo (1997) examined the impact and effectiveness of educational intervention on actual computer-related work by measuring the effects of ergonomic training both on the immediate and the long-term knowledge of ergonomic principles. In Rizzo's study, an ergonomic seminar was conducted and compared among groups without ergonomic training. It was found that the ergonomic training program increased the user's knowledge of the correct use of the computer equipment both for the short-term and the long-term goals to reduce MSDs.

Joines (1995) proposed a methodology called the Expanded Product Comparison (EPC), which is a modified version of the Design for Assembly & Maintenance (DFA/M) technique that intended to reduce the risk of MSDs. The study was attempted to quantify the potential MSDs risk associated with assembly, routine maintenance, and use of a product. The models were analyzed and recommendations were made on potential problems for each assembly task, for improvement at the product design stage. The method focused on the reduction of MSDs risks in the beginning of product/process design, a good preventive solution. The method did not show whether the improvement in product design has reduced the MSDs incident or cost in the workplace.

Prediction models for MSDs were developed by researchers using various approaches, but the link towards performance forecasting and evaluation, which is critically needed for cost effective analysis, remains unknown. *McCauley (1995)* developed a fuzzy rule-based expert system for predicting occupational illness and injuries of the forearm and the hand. The Analytic Hierarchy Processing (AHP) to assign relative weights was used, in order to identify risk factors. *Miller (1995)* used a stress-strength interference model to predict MSDs probabilities. The reliability engineering techniques was used to quantify tendon properties and other bio-mechanical aspects of MSDs. Grip force and wrist angle were used in the model to predict the probability of MSDs. The results were compared to such work from *Armstrong (1982).*

Even though some quantitative measures of ergonomic intervention have been investigated using videotape, it is still unclear how to assess the information gathered in terms of economic effects and injury prevention. *Wells et. al., (1994)* describes an approach to assess the exposure of risk factors for the development of WMD. By video taping to identify risk factors for both acute and chronic injuries in the workplace and monitoring muscle activities, quantitative information necessary for exposure measures is found. Researchers can categorize the risk of a worker for a specific job and qualitatively assess different type of risk impact by using Well's checklist of risk factors and their screening method.

Killough (1995 and 1996) developed a risk index to rank construction tasks where the risk factors are limited to repetitive movements, awkward posture, force, duration and use of tools. A risk index was used to compare against a subjective questionnaire. The risk index ranges from 0 to 5 for each risk factor where the rank is found from adding the total risk indexes for each construction task together. The author uses the risk indexes as quantitative measures, but the determination of each index rating is determined subjectively except for duration and repetition which were rated by time. *Killough (1996)* mainly focused on the construction industry, where research showed seven common MSDs: CTS, tennis elbow, trigger finger, arthritis of the thumb, tendonitis of the wrist, and vibration syndrome. Finally, *Kemmlert (1995 and 1996)* developed a checklist called PLIBEL, which was used as a screening instrument constructed to identify working conditions and risks that may have effects on musculoskeletal systems.

Recently, a more macro approach in ergonomic preventive programs has been developed, for example, the participatory ergonomics program approach. *Moore (1997a, 1997b, and 1998)* investigated the effectiveness of the participatory approach in solving problems related to musculoskeletal hazards in a meat product corporation. *Kuorinka (1997)* described the tools for participatory ergonomics, an approach resulting from several trends such as the society and the organization of production and development of ergonomics from 'micro' to 'macro'. Simulation was used as a tool to explore workplace components.

Gardner (1995) studied the participatory ergonomic program in the Intel Mask Operation (IMO). The IMO implemented a comprehensive ergonomics program in 1993 including training programs for all clean room personnel. The IMO conducted a comprehensive ergonomic evaluation for all of the equipment, operations and procedures used in manufacturing. The employee interviews were conducted and technicians performing daily tasks were videotape recorded, the participatory ergonomic team responsible for work design and equipment installation was included in the study. Analyses from the videotape have been used in analyzing tasks and identifying potential risk factors associated with each task. Gardner used a simple scoring system to identify manufacturing operations with the highest ergonomic risk.

2.3 Methods in Justifying Ergonomic Intervention

Corporations usually value investment in terms of monetary values. Therefore, ergonomic projects must be competed with other projects against the company's limited resources. "Show me the money" is the main theme even though the health and safety of workers should be the top priority. Ergonomic cost justification methods will help managers to decide on the allocation of funding as well as the project selection. It is often that the ergonomic solutions must be justified in order to receive budget for implementation.

In order to justify ergonomic intervention, one must understand how to measure benefits gained through ergonomic intervention. The benefits gained can be achieved by cost reduction. *Brady (1997)* has done a review of the health and safety cost impact to a corporation and defined the cost into two categories: first, the direct and indirect costs related to specific illness or injuries, second are the indirect costs that are related to other health and safety requirements but not to a specific illness or injury. *Chang (1993)* has proposed alternatives for quantifying the cost of occupational injuries and their potential impact compared with traditional statistical tools such as disabling frequency and severity rates which relate to workdays lost. *LaBelle (2000)* introduced a template for measuring the total costs of accidents using an incidence rate. The study defined accident costs into direct and indirect costs.

Another cost measure identified as benefiting from an ergonomic project is the insurance related cost. *Everett and Thompson (1995)* explained how the calculations of insurance premiums are performed where the effect on premiums is the Experience Modification Ratings (EMR). The author exposed the impact of employer's workers' compensation costs. The article is geared towards the construction industry, but it can be applied to other industries. The author described how the Workers' Compensation Insurance (WCI) standard premium is calculated using the manual rate, payroll units, and EMR (a factor that is used to account for the loss experience of each employer and is used to modify past experience). In addition, it was described that the manual rate was based on the frequencies of losses for a particular type of work classified by the code (SIC). Also, the study is illustrated illustrates that the rates for each SIC code were based on the claims that have been filed, while the manual rates give an indication of the risk associated with each work classification. The purpose of EMR is to help improve the prediction of future losses based on past experience. It can be observed that the EMR can act as an incentive for an employer to improve his or her safety record. No study has been done to link the cost of ergonomic improvement that can relate to the reduction or improvement of EMR, which would eventually reduce insurance premiums.

All of the studies above have focused on defining the costs associated with occupational health and safety. Thus, benefits can be gained through the reduction of health and safety-related costs. By understanding the benefits parameters involved in ergonomic intervention, one can justify the investment needed to achieve such an objective. Various methods have been introduced to justify ergonomic intervention. The three major approaches are the cost-benefit analysis, the cost-effective analysis, and the net present value.

Mitchell (1993) has proposed a cost-effective model of a cumulative trauma disorder (CTDs) prevention program utilizing a flow diagram to assign cost among alternatives of ergonomic improvement programs, medical management programs, hazard prevention programs, or training and education programs, compared with no ergonomic intervention. *Clancy (1997)* developed a classification test for analyzing the cost-benefit low back pain intervention.

Alexander (1998) used a value-cost matrix as a tool to identify the cost effectiveness of ergonomic projects. His decision criteria are determined by choosing projects with low cost and high effectiveness. He has categorized benefits of ergonomic projects into six groups: avoidance of current losses, enhanced existing performance, enhanced quality of work-life, reduction of human errors, reduction of injuries, and the reduction of design and acquisition costs. Such findings can be used as benefit factors gained from ergonomic projects.

Lanoie & Tavenas (1996) provided the cost benefit analysis and economic analysis of a participatory ergonomics program to reduce back-related disorders in terms of savings in direct and indirect costs. *Helander and Burry (1995)* showed a cost effectiveness resulting from a systematic approach to ergonomics improvement of manufacturing facilities. Some qualitative models using utility theory, for example, work done by *Rouse (1992)*. A more meaningful cost justification that linked ergonomic intervention to other performance factors such as productivity is the work of *Oxenburgh (1997)*. He uses cost benefit analysis incorporated with some activity-based costing (ABC) concepts.

Riel and Imbeau (1995b, 1996) have done pioneer work related to justifying ergonomic investment by utilizing activity-based costing to assign cost to department and workstation levels. They have developed a framework by classifying three main categories as cost pools: insurance-related costs, work-related costs, and perturbation-related costs. These are used as building blocks of a general approach designed for the economic justification of health and safety investment. Sensitivity analysis of the net present value (NPV) was done based on interest rate changes and cash flow generated by the project.

Their recent work *(Riel and Imbeau, 1997)* applied the model as a case study to justify the investment of a new hydraulic table that in theory will reduce work-related exertion at the workstation. However, the NPV analysis was shown that such investment found to be unattractive due to a negative NPV. They related the cost to a reduction in insurance premium. Some limitations of their model are the ability to predict a specific type of accident that is likely to occur, the number of accidents that can be avoided after the investment, and the amount of injury cost credited to the firm for individual accidents. The sensitivity analysis of NPV was done based on interest rate and cash flow generated by the project. *Riel & Imbeau (1995a and 1995b)* had developed an Activity Based Costing Model for health and safety cost by specifically focusing on the insurance cost category. A detailed cost driver analysis was performed, first by identifying the nature of cost drivers and their root causes. They used the method they developed called Actuarial Analysis. The cost object is the organization, the number of accidents is the activity driver, and the injury cases consume health resources, which generated compensation costs paid by the insurance company. The other two categories are the work-related cost and the perturbation cost. The linkage between ergonomic improvement that should act as a cost-driver towards the insurance cost was not included in their study.

Later Riel & Imbeau developed an evaluation process for ergonomic projects. Their model has six stages: H&S cost identification, H&S cost behavior assessment/cost function development, H&S cost allocation procedures, cash flow profile/estimation of investment, investment economic return evaluation (NPV, IRR, payback period and economic risk analysis) and audit of investment. For each stage they developed tools for such analyses. The main point of such study is the cost function development that are used for understanding the behavior of H&S which are insurance related, work related and perturbation related cost. The three steps recommended for analyzing H&S projects are ergonomic analysis of workstation, statistical analysis of accidents (database are used in linking workstation characteristics to potential accidents) and insurance-related cost functions (insurance bill, preliminary adjustments and definitive adjustments). The main focus of the work was still geared towards defining the cost structure using a simple discounted cash flow method was utilized for valuing a single project.

Andersson (1992a and 1992b) gave some guidelines for economic evaluation using a traditional economic engineering approach for evaluating ergonomic solutions and the ranking of projects, to accept/reject a project, and controlling cost. He identified key cost saving parameters in ergonomic projects, which are the labor turnover, absenteeism, spoiled and defective goods, and productivity. Labor turnover costs are such as acquisition cost/hiring costs, development costs/training, separation costs/vacant position costs. Absenteeism can be identified as cost resulting from accidents and MSDs such as compensation cost and medical cost. Spoiled and defective goods determine the annual total number of units and cost for spoiled goods. Productivity can be identified through motion and time studies.

Alexander (1994) provided an overview of approaches for the justification of ergonomic expenditures which consisted of economic analysis techniques such as benefit cost analysis, rate of return, NPV, comparison losses/gains, and surrogate economic analysis such as cost/effectiveness. In addition, he also recommended the ranking system for risk such as priority systems, risk score, and management by objective, required Expenditures: losses payment, regulatory compliance, allocation of funds: budget allocation, unconstrained budget, investment: safety cost, portfolio analysis, and human resource accounting. Alexander recommended six areas to find cost savings: workers compensation cost, cost of traumatic injuries, performance measures, quality of life, and design it right the first time. He pointed out that the most powerful technique in justifying safety and health is by looking it as investment rather than cost. This approach is a novel concept, and requires support data that is not immediately available nor is widely used. Further exploration of this technique may be helpful to the safety and health community.

2.4 The Limitations in Justifying Ergonomic Projects

Difficulties arise in dealing with the cost justification of an ergonomics program due to the fact that the relationship between the cause and occurrence of MSDs is not fully understood. Since MSDs often develop over time, which makes it very difficult to attribute the disorders to their contributing factors. In addition, researchers are yet to quantify the amount of dose changes on risk factors that can directly affect the MSDs occurrence. In other words the dose-response relationship between risk factors and the development of MSDs have yet to be determined. Furthermore, health and safety related costs often are not defined precisely and accounting systems have not been designed to capture the costs incurred from health and safety problems *(Alexander, 1994; Riel and Imbeau, 1995a and 1995b; Brady, 1997; Lanoie and Tavenas, 1996).* Financial data to assess ergonomic interventions is often missing or difficult to keep track of *(Riel and Imbeau, 1996; Rouse and Kenneth, 1997).* The accuracy of the cost estimate is difficult to achieve and often, in order to seek management approval, an over-estimated ergonomic benefit is applied *(Lyon, 1997).*

Even though there have been studies showing the cost associated with health and safety *(Brady, 1997)*, they provide only guidelines to fill-in information (template format) related to health and safety costs based on a recommended cost definition. To use the templates, companies would need to have systems to collect such information in place, for example, the OSHA's 200 log. However, the information collected is not utilized for studying ergonomic project valuation. The reasons may be because of incomplete data: the data needed for ergonomic justification is not collected; or the structure of the information collected does not provide ease of use. In addition, only few references exist for companies to compare their health and safety costs to other similar industries. The investments' data in ergonomics programs are difficult to estimate due to lack of information. As a consequence, ergonomic justification can be unreliable. The method for justification itself may not be appropriate to measure complex ergonomic intervention such as the OSHA's former ergonomics standard.

These roadblocks may influence decision makers in the field to invest in low-cost solutions that have short-term implications and often do not solve the problems permanently or even in a significant way *(Riel and Imbaeu, 1997; Alexander, 1998).* Given the limited knowledge about MSDs and difficulties in estimating costs incurred in an ergonomic project, more research is needed to study the cost/benefits justification for ergonomic projects *(Macleod, 1996; Mitchell, 1996).*

The existing ergonomic cost justification methods seen in the literature have both advantages and disadvantages. The commonly used ergonomic justification method is the discounted cash flow method (DCF), which uses a specific discount rate to discount the cash flow and calculate the project net present value (NPV). The DCF method is most likely to fail in cases where the investment presents a foundation project for future expansion in a highly uncertain environment (*Kogut and Kulatilaka, 1994*). On the other hand, for projects with incredible value or lack of value, projects that have no follow-up opportunities, or projects with little uncertainty, the DCF method is found to be enough to help managers make correct decisions whether to invest or not.

For ergonomic projects, it would be misleading to say that such a project is incredibly good or bad since the benefits gained in monetary amounts from such projects are not known for certain. Benefits gained from ergonomic projects are highly uncertain since the benefits are difficult to estimate. It would not be appropriate to use the DCF as an ergonomic cost justification because of the following limitations.

One major problem in justifying ergonomic investment is that the net present value of the benefits and cost may show negative values, especially for ergonomic intervention with high investment costs. The DCF method can undervalue an ergonomic project because it does not include the value of the opportunity to make changes when necessary. It can be observed that, in common practice, ergonomic projects are sequentially implemented, based on the outcome from their predecessors. The NPV approach does not capture the opportunities of follow-on investments. When follow-on investments incur high capital expenditures, the value of the whole project can be unattractive. One of the examples is found in *Lanoie and Tavenas (1996)*, where they investigated the costs and benefits of participatory ergonomics. The study listed the cost of ergonomic intervention and estimated the benefits gained from the reduction of illness cases. The NPV method was used to determine the value of the project. The results were shown that in order for the project to be justified by a positive NPV, projects needed to reduce the discount rate or add five more years of benefits gained to the NPV calculations.

Another example is found in the work from *Riel and Imbeau, (1997).* They showed a framework to justify a single investment using the DCF method with sensitivity and risk analysis to evaluate uncertainty in investment parameters such as cash flow, and interest rate. They found that the initial cost of ergonomic projects should be as low as possible in order to minimize the risk of negative return for the project value. *Riel and Imbeau (1997)* suspected that it might be the reason why costly ergonomic projects were often turned down. *Alexander (1998)* found that it is necessary to identify the full amount of benefit in order to offset the cost.

In addition to the fact that the DCF method may undervalue investment projects, the DCF method gives now or never types of investment recommendations. It is because that the NPV decision criteria rely mainly on the expected cash flow and required rate of return. The DCF approach assumes a fixed scenario in which a company starts and completes a project which then generates cash flow during some expected lifetime without any contingencies for deferring or abandoning a project if conditions are not as expected.

Managers should have a portfolio of ergonomic investment alternatives, including its value, in making decision on ergonomic intervention. Whether the investment is in sequence, parallel or even a stand-alone project, management flexibility to defer or abandon an ergonomic project should be taken into consideration as well as the ability to monitor and respond to certain changes that may arise in the future. The ability to justify the cost and effect of each ergonomic project in financial terms can significantly affect management decisions in deciding whether or not to implement ergonomic projects.

2.5 Decision Tree Analysis

Decision tree analysis (DTA) is an approach for analyzing sequential investment decisions when uncertainty of future outcome has effects on current project valuation. Decision tree analysis helps managers to structure decision problems by forcing them to identify all of the possible scenarios and the interdependencies between immediate decisions and subsequent ones. All possible alternative courses of action and their outcomes including probability distributions are laid out in advance based on the information at the current time. Such method is considered promising for evaluating complex sequential projects under uncertainty where the objective is to maximize the risk-adjusted expected NPV. Based on the expectation of cash flow at each discrete point in time, decision tree analysis also has the ability to measure the value of management flexibility with the assumption that a constant risk-adjusted discount rate is applied.

Nevertheless, in order for a project to compete with other investment decisions, financial theory stresses that the firm's investment opportunities are competing with securities that stockholders can buy or sell in financial markets. Assuming that all investment projects are analogous to a mini-firm with all-equity financing, investors are willing to invest or reinvest in the company's project only if such project can do better, risks considered, than investors can do on their own in financial markets. With such assumption, the accuracy in the determination of project value would be critical since the project is competing not only among internal projects but against investments in financial markets as well. Decision tree analysis lacks the ability to determine the appropriate discount rate, but could avoids problem by assuming a constant risk-adjusted rate.

When investment opportunities are involved in multiple follow-on projects (in stages), and when a constant discount rate is applied for the initial stage, the rate should not be used as the discount rate in the follow-on stage. The reason is that some future uncertainties about the follow-on stage, such as the future cash flow, are better known, so the risk involved should be reduced. The result of the reduction in the risk involved causes a different risk-adjusted discount rate as compared to the discount rate used for the initial stage. The problem of finding the proper discount rate is one of the limitations of applying DTA to value complex sequential projects when competing with available investment alternatives.

On the other hand, some researchers suggested trying to use a risk-free rate and to achieve conclusion by examining the probability distribution of NPV. While it would be inconsistent to build a forward decision tree using actual probabilities and expected rate of return but then move backward discounting at the risk-free rate. Thus, by valuing projects using an options approach, such problems in figuring out the discount rate are eliminated. The project value identified through an options approach can be used to compare against competing internal projects as well as investment in financial markets. Other DTA weaknesses are the size and complexity of the tree that can be combinatorial explosive, large, get complex quickly, and required knowledge of joint probability distribution *(Lander, 1997).*

2.6 Real Options and Their Application Review

An option is defined as the right, without an associated symmetric obligation, to buy (if call) or sell (if put) a specified asset (e.g., common stock) by paying a pre-specified price (the exercise price) on or before a specified date (the expiration or maturity date) (*Trigeorgis, 1993d*). Stock options for example, are the most familiar type of financial option. The fixed price in the options contract at which the holder can buy or sell the underlying asset (stock) is called the strike price or the exercise price. Exercising an option is the act of buying or selling the underlying asset via the options contract. The expiration date is the maturity date of the options contract. After this date the option will not be valid. American options may be exercised at any time up to the expiration date, while European options can be exercised only at the expiration date or the maturity date.

A call option gives the owner the right to buy an asset at a fixed price during a particular time period. This right to buy an asset without an associated obligation has value that can be determined based on the exercised price, the time to maturity, the value of the underlying asset (based on its volatility), and the risk-free interest rates. The value of a call option is derived from the fact that the future value of the underlying asset exceeds or falls below the exercised price at the time of expiration. If the value of the asset is less than the strike price, the option will not be exercised and will be worthless. If, on the other hand, the value of an asset is greater than the strike price, the option is exercised. The gross profit on investment is the difference between the asset value and the exercised price. The net profit is the difference between the gross profit and the price for the call option.

For example, assume current Dell stock is at $100 per share. A person may purchase a call options contract at $50 (option price/option premium) to buy 100 units of Dell stock at $100 (exercised price) 1 year from now. In the case that the stock moves up to $105 at the maturity date (one year from now), the holder of a call option makes a profit equal to $450 [($105-$100)*100 - $50]. If the stock moves down to $95, the holder of the call option lets the option expire losing the $50 option premium. However, if one were to buy 100 shares last year and the price moved down to $95, one would lose $500 a year later. Table 2.1 shows a summary of the transaction in a call option, while the payoff diagram in Figure 2.1 illustrates the cash payoff on an option at expiration. Both call and put options on stock have values that are traded on a regulated market such as the Chicago Board Options Exchange. Tremendous work has been done in the past to determine the pricing of call and put options, *Black and Scholes (1972)* introduced a closed form solution for valuing European options; *Cox, Ross and Rubinstein (1979)* introduced the binomial approach to options valuation that is considered more intuitive and able to value other types of option such as the American call option; *Geske (1979)* introduced method to value compound options. The steps to find the price/value of a call/put option can be seen in Appendix B.

Table 2.1 Summary transaction in a call option.

Type	Now	At Expiration
Buyer of call option	Pays the call price and gets the right to exercise.	If asset value (S) > strike price (K), buyer exercises. Gross profit = S – K Net profit = S – K – Call price
Seller of call option	Receives the call price and agrees to deliver the asset at the exercise price if the buyer demands it any time before expiration.	If asset value < strike price Buyer does not exercise Buyer's loss = Call price Seller's price = Call price

Source: Damodaran, 1997

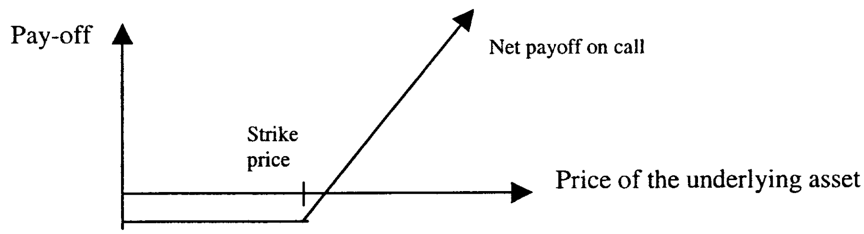

Figure 2.1 Payoff on a call option

Another type of option is the embedded option in capital investment projects. Capital budgeting is the process that a company goes through in order to plan for future investment. Companies would rather invest in projects that create value to the shareholders. Competing projects are also compared against the return invested in other financial instruments such as securities. The conventional tools for project valuation are such as the net present value (NPV), the return on investment (ROI), and the payback period. The NPV method and others assume that the project under consideration is executed and continuously follow the path of the proposed plan until the end of the project's life. In addition, a risk-adjusted discount rate is assigned to reflect the time value of money as the project progresses along its life cycle.

Recently, researchers have argued that such tools lack the ability to capture the value of the project's flexibility and the dependency between sequential projects *(Myers, 1984; Myers and Majd, 1990; Trigeorgis and Mason, 1987; Brealey and Myers, 1991; Trigeorgis and Kasanen, 1991; Agman, 1991; Kulatilaka and Marcus, 1992; Smith and Ankum, 1993; Kemna, 1993; Kogut and Kulatilaka, 1994; Ross, 1995*). A project's flexibility can be described as internal and external to the project. The *internal flexibility* is the management's ability to modify or alter the project as it goes through the project's life cycle such as increasing, reducing, deferring, accelerating, switching or even terminating the project when the future outcome changes. The *external flexibility* of a project is the potential future opportunity that the project itself can create for another project that may not have been possible originally. One example of external flexibility can be found in Research and Development (R&D) investments. The R&D project creates future opportunity to invest in production and commercialization in order to gain profit. Without the investments in R&D, it would be impossible for a company to invest in the production and commercialization phase of a product. Therefore, the R&D investment gives the company the option to invest in the production phase when the market is favorable and not to invest in the production phase if market turns unfavorable *(Morris, Teisburg, and Kolbe, 1991; Hemantha and Park, 1999).*

The internal and external flexibility of a project affects the projected cash inflow and the determination of the expected NPV. One can observe that the distribution of the net present value using the discounted cash flow method ends up with a bell shaped curve with the expected NPV in the middle. However, because management has the flexibility to modify or improve the project's upside potential while limiting the downside loss as time moves forward, the expected cash inflow increases and causes the distribution of the expected NPV to be skewed, bringing the expected NPV towards the positive side. The differences in the expected NPV between including and excluding management flexibility can be measured quantitatively using the real options approach *(Trigeorgis, 1993; Trigeorgis, 1996; Busby, 1997; Amram and Kulatilaka, 1999).*

Dixit and Pindyck (1995) argued that the NPV method assumes either investment are reversible (expenditures can be recovered if condition turns bad) or irreversible (if not invest now, the opportunity are lost forever) while in reality investments are mostly not reversible and being capable of deferring. Their study suggested that investment expenditures are irreversible when they are specific to a company or industry. By deciding to go ahead with such irreversible expenditures, the firm kills the option of waiting for new information that may affect the timing of the investment. The lost opportunity (option value) must be accounted for. Therefore, the NPV of a project must exceed the cost of the project by an amount equal to the value of keeping the option to defer alive instead of just a positive NPV.

Dixit and Pindyck (1995) suggested that capital investment decisions are considered to be irreversible and have the ability to delay investment. Thus, an option to delay investment will increase the project's value. The study was concluded that by deferring an irreversible investment opportunity, the option of waiting is created and could be quantified similar to a financial call option. The author showed that there is a value in waiting for more information and also a value in speeding up investments. However, such values are not reflected in standard NPV calculations. When conventional valuation tools cannot capture the project's flexibility, as a result of excluding flexibility, the value of the project is underestimated.

Cheung (1993) suggested based on the real-options literature that capital budgeting decisions can be modeled using options analogy since the discounted cash flow approach cannot justify the strategic reasons for investment in future growth and fail to account for the value of active management. The author briefly described five types of real-option: a timing option, a growth option, a shut-down/produce option, an option to alter input/output mix, and an abandonment option.

Luehrman (1998b) also described how option pricing could be used to improve decision-making for the sequencing and timing of a portfolio in strategic investments.

The author developed a matrix called "option space", which is based on the *value-to-cost ratio* plotted against the *volatility rate*, and defined the matrix into six regions in which management can use as decision making tools for evaluating investment projects. *Luehrman (1998a)* uses his framework to bridge the gap between practicalities of real world capital projects and higher mathematics associated with formal option-pricing theory, by calculating the value of investments based on the two types of ratios: volatility and value-to-cost ratios.

Other researchers such as *Kogut and Kulatilaka (1994)* developed a set of heuristics that viewed organization's capabilities as generating platforms to expand into new but uncertain markets. The author argued that these capabilities are considered options because they are investments in opportunities and stated that platform investments are options on the future. The authors concluded that the value of a platform investment is determined by the same factors that are used to price financial options, such as the variability of future market value, the maturity dates of contracts, and the exercise price of an option. It was recommended that, by recognizing that an investment opportunity is like a financial call option, one can understand the role which uncertainty plays in the timing of capital investment decisions.

The concept of seeing investments as options is well known as "Real Options", since it deals with physical or human assets as opposed to financial instruments such as stocks and bonds (*Trigeorgis, 1993; Dixit and Pindyck, 1995*). The real options approach is capable of quantifying the value of an opportunity to gain the upside potential while limiting the downside risks. Companies have opportunities to invest in capital projects and must decide how to exploit those opportunities effectively. They must consider the value of opportunities in making optimum decisions.

The value of having the option to wait or defer investment can be critical in determining the optimal time to invest *(Myers, 1984; McDonald and Siegel, 1985 and 1986)*. The method used to value the option to defer an investment is similar as the method for valuing an American call option where the value of investment at the end of the deferring period are treated as if they were stock price, the investment expenditure at the end of the deferring period is similar to an exercise price of an option, the loss cash flows while waiting are analogue to dividends on stock. The ability to defer an investment project may come from the rights of a lease, a patent, or an insured contract *(Dixit and Pindyck, 1995; Lander, 1997 and 1998; Trigeorgis, 2000)*. The value of the option to defer by waiting for new information to resolve appears in various real option literature *(McDonald and Siegel, 1986; Trigeorgis and Mason, 1987; Paddock, Siegel, and Smith, 1988; Trigeorgis, 1990; Kemna, 1993; Dixit and Pindyck, 1995)*.

Another example of company's investment opportunity is the option to expand investments or growth-option. An investment in first-generation high-tech products can serve as a launch for future development of a second-generation product despite the negative NPV of the first-generation product investment. Unless the firm makes such initial step, other subsequent generation would not be feasible. The investment in the first-generation product creates the opportunity for future development (growth-option). Such creation has value that can be measured using call option analogy where the cost of the second-generation product is analogous to the exercised price, the maturity date are defined by the time that the company has the advantage based on the knowledge of the first-generation before competition may enter the market, and the possible benefits gained from the second-generation product as the stock price. The value of growth option is critical for strategic planning and have been explored by various researchers *(Myers, 1984; Trigeorgis and Kasanen, 1991; Kogut and Kulatilaka, 1994; Faulkner, 1996; Mcgrath, 1997; Taudes, 1998; Chatterjee and Ramesh, 1999; Hemantha and Park, 1999).*

In the past, real-options approach has been used to quantify various investment projects with considerably uncertain cash flow estimate such as the oil industry *(Paddock, Siegel, and Smith, 1988; Kemna, 1993; Chorn and Carr, 1997; Dias, 1997)*, the natural resources investment *(Trigeorgis, 1990 and 1993a; Laine and Oy, 1997)*, the power generating plants, as well as decisions on when to close a mine, the growth option of R&D projects *(Morris, Teisberg, and Kolbe, 1991; Faulkner, 1996; Hemantha and Park, 1999)*, the expansion of flexible manufacturing systems *(Kumar, 1995; Khouja and Kumar, 1999)*, the valuation of flexibility in production systems *(Kulatilaka and Marks, 1988; Triantis and Hodder, 1990; Cortazar and Schwartz, 1993)*, information technology growth option *(Kumar, 1996; Mcgrath, 1997; Taudes, 1998; Benaroch and Kauffman, 1999; Chatteree and Ramesh, 1999)*, and investment decisions related to telemedicine systems *(Cameron, 1998)*. These previous work clearly suggest that the real options approach have been studied and applied in various investment decisions especially when future benefits are not known with certainty.

The value of real options is derived based on the value of the project as oppose to the option itself. In other words capital budgeting decisions can be viewed in terms of options or contingent claim analysis (CCA) *(Mason and Merton, 1985)*. In order to determine the value of an option, one must be able to observe the value of the underlying asset. However, in the case of real-options, difficulty arises because the underlying assets are not financial assets where the value can be found from the financial market, but they are assets such as potential cost savings, revenue opportunities, reduction in MSDs incident rate, decrease in insurance premiums or increase in productivity. In addition, there can be interactions among sequential projects, also management have the flexibility to alter stages of the project which makes it differ from financial option, thus, make real option more difficult to quantify. The effects of project' interaction and interrelation affects the value of real options *(Trigeorgis, 1991b and 1993c; Childs, Ott and Triantis, 1998).*

The limitations in applying real options are mainly due to the difficulties in estimating the value of the parameters needed for real options valuation such as the uncertainty of the investment cost, and the expiration date of real-options, which is difficult to define. The time for real investment to expire is mostly more than a year as opposed to financial option, and the level of difficulty is much higher for real-option in determining investment costs compared to the exercised price of a call option. Then, there are the issues of the stochastic process of the underlying asset price, which is not fully understood. Even though *Lander (1997)* proposed influence diagram as an alternative for valuing investment under uncertainty, yet, the method is appropriate only if uncertainty can be modeled by a set of conditional probability distribution, the method cannot solve large problems, the method requires dummy values for modeling asymmetric decision problems, and the arbitrariness of discount count rate which is a similar drawback as the DTA method *(Lander and Pinches, 1998).* Nevertheless, *Leslie* *and Michaels (1998)* believed that real options could provide a systematic framework that will also serve as a strategic tool, and that it is in this strategic application that the real power of real-options lies. It was indicated that to quantify strategic thinking by the integration of real option with strategic planning is one of the main benefits of real options *(Trigeorgis and Kasanen, 1991).*

Recently, real options technique was applied to demonstrate the potential financial savings from investments in telemedicine systems using simulated data *(Cameron, 1998).* The motivation of the study was to identify the conditions where telemedicine is financially viable as a component of a healthcare delivery system and to estimate the financial effects that management flexibility contributes to their cost-effectiveness. The study can be assumed that the future of telemedicine systems depends heavily on its financial viability. The author stated that medical center's management can (but is not obligated to) make an investment decision to obtain a productive asset and such investment opportunity is available for a certain period of time, similar to the rights without obligation of an options contract.

Cameron (1998) introduced the option to defer investment in telemedicine system until the nature and level of reimbursement for telemedicine services are better known. It was also investigated the option to alter telemedicine systems by adding spoke sites when future looks promising, or terminating spoke sites if future condition turns unfavorable. The option to switch the use of telemedicine system for a non-clinical function (such as administrative or educational usage) when conditions turn out unfavorable was also introduced. The uncertainties related to the valuation of telemedicine systems was mainly the reimbursement level factor, others include healthcare structure (managed care settings vs. fee for service), the volume of use, and the mix of services provided. The benefits of telemedicine systems are such as the reduction in patient transfer costs, patient travel costs, and patient/family productivity.

Even though the differences between telemedicine and ergonomic investment can be observed in terms of the physical project as well as the parameters used for measuring the benefits, the similarities are that both focuses on improving health and safety conditions and the potential benefits of such investments in terms of medical related savings are not known with certainty. Telemedicine projects are considered to be health and safety related as well as ergonomic interventions. In the following study (Chapter 4), it is suggested that it would be possible to use real options as a tool to value ergonomic intervention projects in some circumstances.

Real-options valuation has its advantages when the decision depends on an uncertain outcome in the future; when the value of the current project is derived from a future follow-on project rather than its current cash flow; when the ability to modify or alter future projects exists; when investment projects are irreversible and the uncertainty is large enough that it is sensible to wait for more information before committing capital; when there is a need to quantitatively compare between strategic investment and financial market returns. A firm may acquire the *option to invest* (real option) through its intellectual property rights, organization structure, ownership or rights to land or natural resources, reputation, technology knowledge, market position, organizational capabilities, or employees *(Lander, 1997; Trigeorgis, 2000).* One example of real options in ergonomic projects is the option to implement ergonomic solutions, which is created by the knowledge of the working environment and the understanding of MSDs problems (these problems are examined in detailed in Chapter 5, section 5.4). Such knowledge can be acquired through ergonomic checklist, or detailed task analyses. The uncertainties surrounding ergonomic projects benefits are such as the medical costs, the market demand for products that may increase workers repetitive task, or the advances in ergonomic understanding of dose/response.

CHAPTER 3

METHODOLOGY

Work-related MSDs imposes an enormous burden on society in terms of pain and suffering experienced by workers and their families. The extent of the burden imposed by work-related MSDs in the United States was reported as 626,000 cases in 1997. In addition to the pain and suffering, effects of such a burden are the loss of esteem and the reduction in the quality of life that cannot be expressed quantitatively. Meanwhile, the monetary impact of MSDs affects the company's monetary measures and is quantifiable in terms of workers' compensation costs, work-related costs, labor turnover expenses, and productivity/quality losses.

BLS publishes statistical data (*BLS website*) related to occupational injuries and illness, but seldom are such data used for the process of ergonomic intervention decision-making and project valuation purposes. The reason may be that the data are designed for reporting purposes, a passive activity, rather than active for ergonomic improvements. This chapter introduces a framework to estimate the costs related to MSDs problems as well as the estimation of the investment needed to comply with OSHA's former ergonomics standard for the manufacturing industry.

3.1 The Costs Related to MSDs Problems

It is a common practice to use workers' compensation costs, work-related costs, labor turnover costs, productivity and quality losses as indicators for evaluating the costs related to MSDs problems *(Parenmark, et al., 1993; Dahlen, and Wernersson, 1995;*

Macleod, and Morris, 1996; OSHA, 1999). Once MSDs related costs are identified, it becomes easier to project potential savings and benefits. It is generally believed in the ergonomic community that ergonomic interventions enhance productivity *(Oxenburgh, 1991 and 1997; Helander and Burri, 1995)*. But the reasons for productivity/quality improvement may also come from the need to increase production, reduce rework/scrap, and increase product/process quality, rather than to reduce work-related MSDs problems. Sometimes including productivity and quality improvements along with ergonomic benefits may overestimate the benefits of ergonomic interventions. Therefore, the framework will estimate the three cost parameters that are directly related to health and safety: workers' compensation costs, work-related costs, and labor turnover costs due to MSDs problems. In order to estimate the three categories of costs, there needs to be a way of estimating key factors that triggers the costs of MSDs, such as *the number of injury and illness cases for various exposure types* that result in days away from work, and the *proportion of illness types within each type of exposure*.

The exposure types under consideration in this study included repetitive motion, over-exertion, and bodily reaction due to awkward posture. The potential MSDs cases for each type of exposure in any given SIC are estimated by using the future incidence rate (cases per 10,000 full-time workers). Therefore, it is possible to determine the number of potential injury/illness cases for a typical company in a particular industry type. In order to be able to estimate future incidence rate for a given SIC, historical data associated with MSDs incidence rates are collected from BLS website from 1993 – 1997. The reason for selecting such period is because BLS was redesigned in 1992 *(NIOSH, 1997; Murphy, et al., 1996)* to capture more detailed information on the nature of injury/illness (sprain or carpal tunnel syndrome), the part of the body affected (back or wrist), the source of the injury/illness that directly produce disabling condition, and the event/exposure that describes the manner in which injury/illness was inflected (overexertion and repetitive motion). The goal is to have a complete incidence rate from 1993-1997 of each SIC grouped by the type of exposure similar to Table 3.1. With such information, a regression function (when the r-square is significant) or a five-year incidence rate averages can be developed for estimating the potential of MSDs cases in each SIC.

Table 3.1 Incidence rate of MSDs per 10,000 workers based on industry grouped by the type of exposure.

Industry	SIC	Over exertion		Repetitive	Bodily reaction	
		Total	In lifting	Motion	Twisting	Others
Lumber and wood products	24	85.9	42.1	15	14.13	7.06
Furniture and fixtures	25	86.2	54.7	18.8	14.7	7.35
Fabricated metal product	34	95.4	54.9	19.5	16.1	8.04
Industry machinery/equipt.	35	62.1	36	15.3	10.84	5.42
Electronic/ electric equipt.	36	41.1	24.9	20.4	8.61	4.3

BLS provided incidence rate for overexertion and repetitive motion *(BLS Table R8)*. However, BLS does not directly provide the incidence rate of worker's awkward posture. It is assumed that the incidence rates of MSDs due to awkward posture are those of acute due to twisting and bodily-reaction not elsewhere classified (n.e.c.). The incidence rate for bodily reaction injury/illness is derived based on the proportion of bodily reaction from the total cases of over-exertion/repetitive motion provided in BLS Table R31. Table R31 in BLS website reported the number of non fatal occupational injuries and illnesses involving days away from work by event or exposure leading to injury or illness and selected nature of injury or illness. The information related to bodily reaction, over exertion, and repetitive motion was extracted from Table R31 in order to determine the proportion of bodily reaction from the total number of cases for each year, illustrated in Table 3.2. The study found that the average proportion of bodily reaction due to twisting was 0.14 and 0.07 for bodily reaction not elsewhere classified (n.e.c). The proportions are used for estimating the incidence rate for bodily reaction when the number of over exertion and repetitive motion are known. With the known potential cases of injury/illness for a particular exposure (risk factor), next is to estimate the proportion of the nature of illness within each type of exposure cases.

Table 3.2 Bodily injury and illness cases are estimated based on the proportion of bodily injury cases as compared to the total of over-exertion and the total of repetitive motion cases.

Year	Over Exertion	Repetitive Motion	Bodily reaction		Total MSDs	Bodily reaction proportion	
			In twisting	N.E.C.		In twisting	N.E.C.
1997	58.5	8.7	9.1	4.6	80.9	0.14	0.07
1996	62.7	8.8	9.5	4.5	85.5	0.13	0.06
1995	68.7	10.1	10.8	5	94.6	0.14	0.06
1994	76	11.5	11.1	6.6	105.2	0.13	0.08
1993	80.6	12	11.6	6.7	110.9	0.13	0.07

Even though BLS reported the number of MSDs cases grouped by a particular risk factor (exposure type) as well as by the nature of injury/illness, the information regarding the nature of injury/illness cases within each exposure types does not exist. Therefore, the number of cases of exposure grouped by the nature of injury/illness cannot be obtained for any SIC directly from the BLS reports. The *nature of illness* associated with MSDs that are used in the current study are sprain and strain, back pain, carpal tunnel syndrome (CTS), tendonitis, and other MSDs involving nerve (other than tendonitis). The current study estimated the proportion of each nature of injury/illness cases within a particular exposure type using a factor called the Exposure-Illness

Coefficient Matrix (EICM). The EICM was derived using the number of cases-per-exposure and cases-per-nature of injury/illness in a selected industry, from which later the proportions of each nature of injury/illness cases within an exposure type are determined. The proportion of injury/illness cases for each nature of illness is calculated by multiplying the EICM and the estimated number of cases in each exposure group. EICM (proportion of cases for a particular exposure type) being used for estimating the proportion of cases to the nature of illness type is illustrated in Table 3.3. Such information is the critical factor that determines the costs of MSDs including, workers' compensation costs, work-related costs, and labor turnover costs. Components needed for estimating the potential cost of MSDs problems are shown in Figure 3.1.

Table 3.3 Nature of illness proportion based on selected exposure (EICM).

Injury/illness description	Nature of illness code	Over exertion		Bodily reaction		Repetitive Motion
		Total	In lifting	Twisting	N.E.C	
Sprains, strain, tears	021	0.80	0.80	0.83	0.80	0.19
Back pain only	0972	0.054	0.055	0.07	0.03	0.01
Carpal tunnel syndrome	1241	0.00	0.00	0.00	0.00	0.38
Connective tissue	17	0.016	0.013	0.00	0.00	0.25
Tendonitis	1733	0.009	0.007	0.01	0.01	0.15

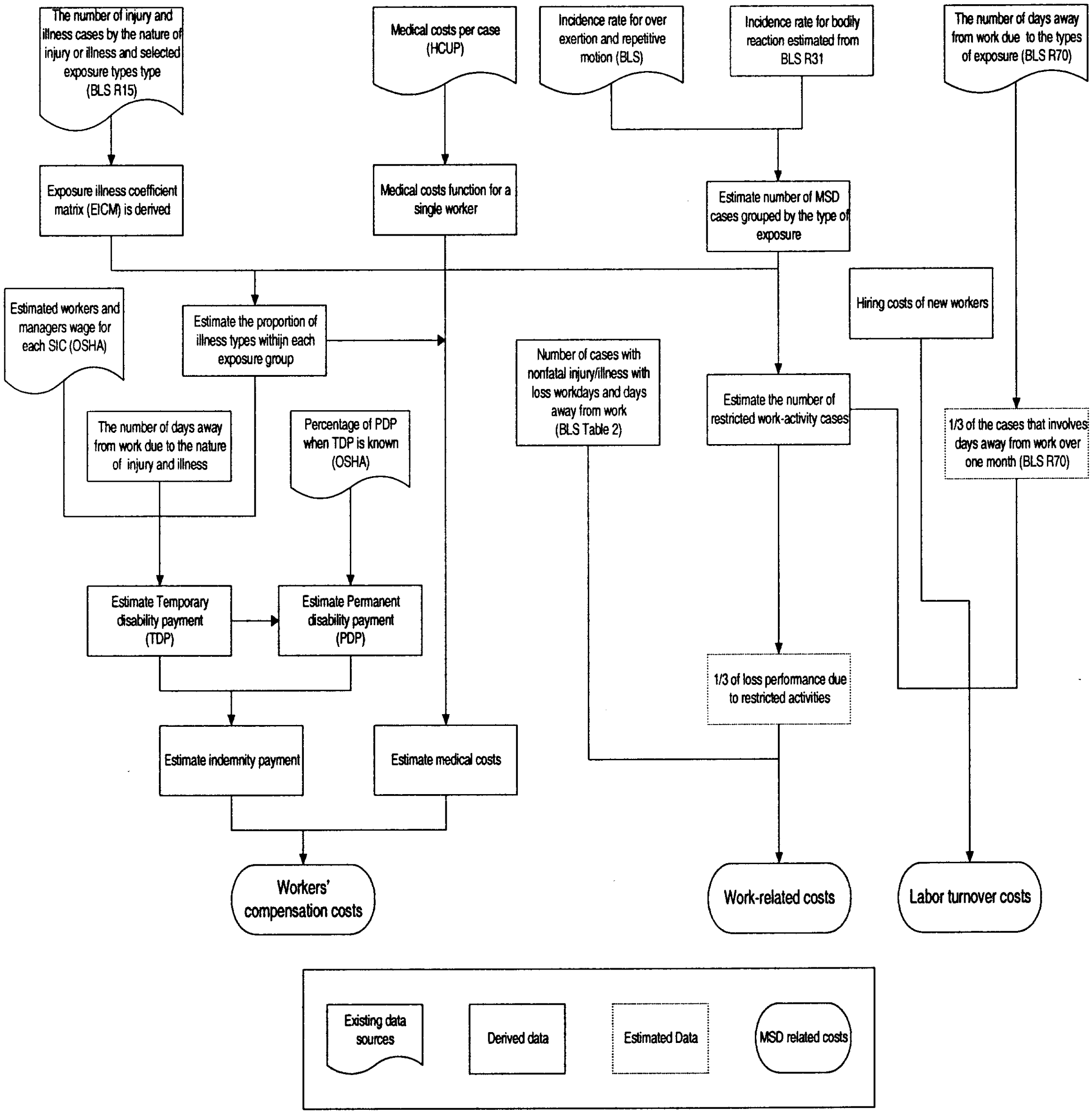

Figure 3.1 Detailed data map of the cost structure, which shows the relationships and components needed for estimating the potential cost of MSDs problems: workers' compensation, work-related, labor turnover cost.

A) Workers' compensation costs: *Workers' compensation costs* are calculated based on medical and indemnity payment that are triggered by the number of MSDs cases. It was assumed that workers' compensation costs will eventually be paid out to the insurance company through the premiums charged *(Everett, 1995).* Medical payments are estimated by multiplying the proportion of workers having MSDs injury (categorized by the type of illness) and the estimated medical expense per case for an illness type. The proportion of MSDs cases grouped by illness type within each MSDs exposure group used for calculating medical expenses was described earlier in the chapter.

The medical payment per case was estimated by using cost data collected from the Healthcare Costs Utilization Project (HCUP-3) from 1993 to 1995. The types of injuries and illnesses selected from HCUP-3, which are extracted from the list of Diagnostic Related Groupings (DRG) and Clinical Classification Software (CCS), are those candidates for WMSDs. The definition of DRG and the categorization of CCS can be seen in Appendix A. The types of injuries and illnesses therefore, included sprain and strain, back pain, CTS, and tendonitis. Medical expenses for a selected injury were estimated by using an average cost during a five-year time frame or a regression function (when the r-square is significant) that can estimate the medical expenses for each MSDs related illness. The study uses a regression function based on CCS categorization for estimating medical expenses for sprain and strain, CTS, MSDs involving nerve, and tendonitis since the r-square each regression is over 0.8. The medical expense for back pain has r-square lower than 0.8 therefore, the study will estimate medical expense based on the average medical costs using CCS rather than DRG categorization because it seems to be closer to the costs reported by earlier study *(Webster and Snook, 1994)*. Table 3.4 illustrates the information for estimating medical expenses due to MSDs injuries and illnesses.

Table 3.4 Average medical costs for MSDs injury/illness by the type of illness for DRG and CCS categorization scheme. Regression Data with r-square above 0.8 are used for estimating future medical expenses while an average medical cost will be used for r-square lower than 0.8.

Types of illness	Diagnostic category	P Value	Regression R-square	The average medical cost of selected MSDs between 1993-1997				
				93	94	95	96	97
Sprain and strain	CCS	0.016	0.968	$5,911	$6,140	$6,219	$6,386	N/A
	DRG	0.525	0.225	$4,858	$5,288	$4,616	$4,720	$7,631
Back pain	CCS	0.311	0.474	$9,714	$11,171	$10,626	$11,082	N/A
	DRG	0.195	0.648	$7,232	$7,808	$3,957	$4,520	$5,213
CTS	CCS	0.096	0.817	$12,665	$12,725	$12,050	$11,937	N/A
	DRG	0.166	0.696	$10,269	$10,752	$7,868	$7,991	$11,109
Connective tissue	CCS	0.008	0.984	$15,868	$16,617	$17,516	$17,962	N/A
	DRG	0.173	0.683	$8,013	$8,529	$6,603	$6,464	$9,193
Tendonitis	CCS	0.020	0.961	$15,105	$15,828	$17,328	$17,783	N/A
	DRG	0.292	0.501	$8,598	$9,266	$6,755	$7,338	$9,929

The indemnity payments typically take two forms: one is the temporary disability payment (TDP), which covers the duration of absence from work before the condition of the injured worker stabilizes; the other is the permanent disability payment (PDP), which compensates the worker for the long-term effects of a stabilized condition. The TDP is estimated using the *average days away* from work due to the nature of the illness (sprain/strain, back pain, CTS, and tendonitis) multiplied by worker's daily wage. BLS Table R67 reports the number and percentage distribution of nonfatal occupational injuries and illnesses involving days away from work by nature of injury or illness and number of days away from work. The *average days away* from work due to the nature of illness shown in Table 3.5 used in the study was derived from BLS website *(BLS Table R67).*

Table 3.5 Average days away from work due to MSDs as a result of the nature of injury or illness.

Exposure types	Average days away from work each year				
	1993	1994	1995	1996	1997
Sprains, strain, tears	11	11	11	11	11
Back pain only	12	12	12	12	12
Carpal tunnel syndrome	22	22	22	21	20
Connective tissue	14	15	15	14	15
Tendonitis	14	14	15	14	15

Then the PDP is estimated from the TDP, by multiplying the TDP by 2.174 (the ratio derived from OSHA's recommended proportion for estimating PDP when TDP is known, *OSHA website*). Figure 3.2 shows the breakdown of workers' compensation claims into medical costs and indemnity payments. Table 3.6 illustrate the output of the estimated workers' compensation cost categorized by the type of injury/illness.

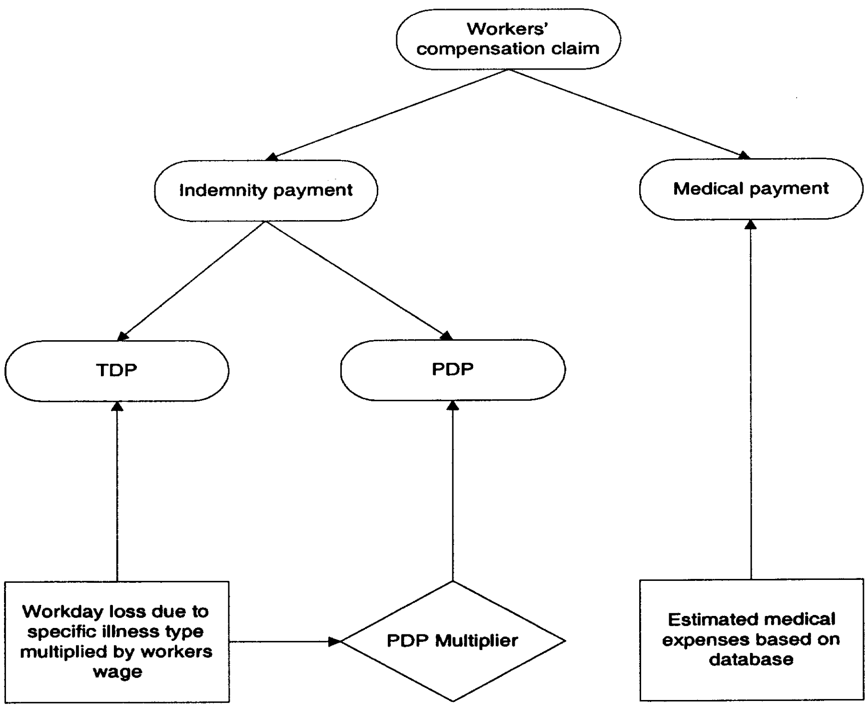

Figure 3.2 Workers' compensation breakdown structure

Table 3.6 The estimated workers' compensation costs that can occur due to repetitive motion problems for the following six years. The example table shows the breakdown into medical costs, temporary disability, and permanent disability payment (the example comes from SIC 2013 with 1000 employees).

The nature of illness	The estimated medical costs over six years					
	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year
Sprain and strain	$4,956	$5,910	$6,816	$7,673	$8,480	$9,239
Back pain	$492	$601	$709	$817	$926	$1,034
CTS	$18,712	$23,406	$28,306	$33,415	$38,731	$44,255
Connective tissue	$20,389	$23,960	$27,201	$30,111	$32,691	$34,941
Tendonitis	$905	$1,051	$1,178	$1,285	$1,374	$1,444
Total medical cost	$45,454	$54,928	$64,210	$73,302	$82,202	$90,912
The nature of illness	The estimated temporary disability payment (TDP) over six years					
Sprain and strain	$856	$1,044	$1,233	$1,421	$1,609	$1,798
Back pain	$57	$69	$82	$94	$106	$119
CTS	$3,572	$4,358	$5,144	$5,931	$6,717	$7,503
Connective tissue	$1,552	$1,894	$2,235	$2,577	$2,918	$3,260
Tendonitis	$70	$86	$101	$117	$132	$148
Total TDP	$6,107	$7,451	$8,795	$10,139	$11,483	$12,827
PDP estimate	The estimated permanent disability payment (PDP) over six years					
Total PDP	$13,277	$16,199	$19,121	$22,042	$24,964	$27,886

B) Work-related costs: *Work-related cost increment* due to WMSDs is calculated based on the number of restricted work-activity cases. Workers who are restricted in work-activities due to MSDs are assumed to perform their duties below their normal conditions. Consequently the work-related cost increment incurred by WMSDs can be derived from the performance decrement from a full capacity level multiplying by the hourly wage. Such costs incurred from the restriction in worker's activity can be avoided by implementing an effective ergonomics program. However, the number of workers who are restricted in work-activities due to MSDs are not directly available from the BLS database.

BLS reports the number of workers who are affected in lost workday cases due to *injuries/illnesses* and *injuries only (BLS Table 2).* It is later derived in the study the number of workers with lost workday cases due to *illness only.* The reason for using illness only to determine the restricted cases due to MSDs is because that BLS categorized the nature of MSDs injuries as illness (except for back pain).

With information on the *total lost workday cases* and *lost workday cases with days away from work*, the number of restricted work-activity cases (with lost workday) are derived. Therefore, a restricted-work coefficient (λ_{rwc}) matrix can be determined and used as a multiplying factor for estimating the number of cases having restricted work-activities for each industry. The information collected from BLS to determine the restricted work-activity cases within the lost workday cases as a result of illness only is illustrated in Figure 3.4. The restricted-work coefficient (λ_{rwc}) was determined according to the number of restricted work-activity cases within cases with lost workdays. Examples of the restricted-work coefficient (λ_{rwc}) for a selected SIC that was derived from BLS is shown in Table 3.6.

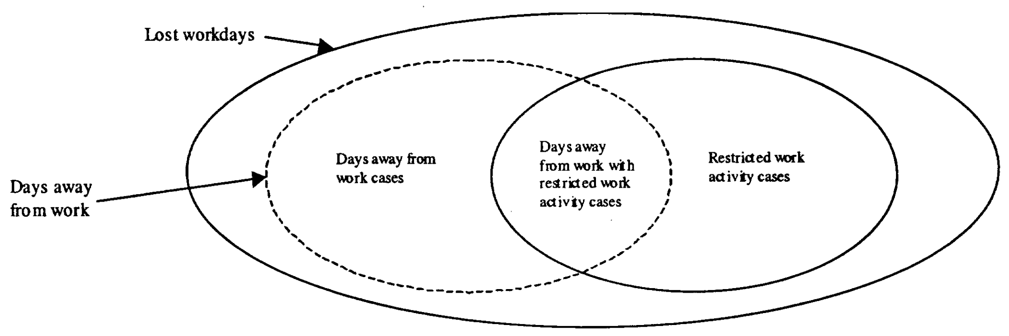

TABLE 2. Incidence rate of nonfatal occupational injuries and illnesses by industry and selected case types, (thousands) **TEMPLATE**

SIC Code	1997 Annual average employment	Injuries and illness				Injuries only			
		Totla cases	Lost workdays		Without lost workdays	Total cases	Lost workdays		Without lost workdays
			Total	Days away from work			Total	Days away from work	
25	510.80	60.50	29.40	14.30	31.00	55.70	26.70	13.30	29.00

Derived table

Illness Only					Coefficient Ratio (c)	
Total cases	Lost workdays		Without lost workdays	Restricted Work Activities	Restricted Work Activities	Without lost workdays
	Total	Days away from work				
4.80	2.70	1.00	2.00	1.70	1.70	2.00

Figure 3.4 Restricted work-activity are derived using BLS Table 2 that reports the number of injury/illness with days away from work, and injury only case. The illnesses only are later derived and restricted work-activity are determined.

Table 3.7 Restricted-work coefficient multipliers.

Industry type	SIC	Restricted workdays (λ_{rwc}).
Lumber and wood products	24	1.3
Furniture and fixtures	25	1.7
Stone clay and glass prod.	32	0.89
Primary metal industry	33	1.36
Fabricated metal product	34	0.86
Industry machinery/equipt.	35	1.21
Electronic/ electric equipt.	36	1.62

The number of restricted-activity cases is obtained by multiplying the restricted-work coefficient (λ_{rwc}) with the number of injury cases. During the restricted-activity period, workers are assumed to perform activities with performance level below their normal capacity. The study assumes that workers will perform at 1/3 below their normal capacity during the restricted-activity period. Work-related cost is estimated by multiplying the number of restricted-activity cases, the percentage of worker's performance with respect to normal capacity during the restricted-activity period, *the average restricted workdays for a given exposure type*, and worker's hourly wage. The average restricted workdays for a given exposure type is estimated from BLS Table R70, reporting the proportion of cases that are involved in days away from work, ranging from one day to over one month for detailed exposure types. Data were extracted from BLS Table 70 (1993-1997) and *the average days away* from work due to the type of exposure are calculated. The days away from work due to MSDs as a result of the type of exposure are indicated in Table 3.8.

Table 3.8 Average days away from work due to MSDs as a result of the type of exposure.

Exposure types	Average days away from work each year				
	1993	1994	1995	1996	1997
Bodily reaction due to twisting	11	11.5	11	11	11
Bodily reaction n.e.c.	12	12	12	12	12
Over exertion total	12	12	11.5	12	12
Over exertion in lifting	12	12	11.5	11.5	11.5
Repetitive motion	18	17	17.5	17	17

C) Labor turnover costs: The labor turnover cost increment due to WMSDs is estimated based on an assumption that workers with loss days over one month may leave their jobs. It directly increases the labor turnover costs if such cases happen. It assumes from this study that one third of such cases will result in a labor turnover. However, there are two groups of potential labor turn over cases, one are the workers with MSDs that involve days away from work, the other are the workers with restricted work-activity cases.

The estimate labor turnover cases are determined by multiplying the proportion of MSDs cases that are expected to result in days away from work and restricted work-activity beyond 30 days, and the number of MSDs cases. Then, labor turnover costs are estimated by multiplying labor turnover cases and the average replacement costs per worker. The replacement cost was estimated by using data from the studies of *Andersson (1992a), Parenmark, Malmkvist, and Ortengren (1993), Dahle'n and Wernerson (1995), and Alexander (1994).* The estimated cost of replacing a worker is assumed to be $500 for companies with 1 to 1,000 employees and $3,000 for companies with over 1,000 employees. Based on the assumption described, the function that describes labor turnover expenses can be seen in equation (1).

Labor turn over cost (Lt) = (1/3) * C * I * W ....(1)

Where C is the proportion of MSDs cases that are expected to result in days away from work beyond 30 days. Such proportions are estimated for both MSDs cases with days away from work as well as cases with restricted work-activity. "I" is the number of illness cases and "W" is the average hourly wage (based on BLS estimates) for a particular worker in the selected SIC. A flow diagram that summaries the framework described earlier can be seen in Figure 3.5.

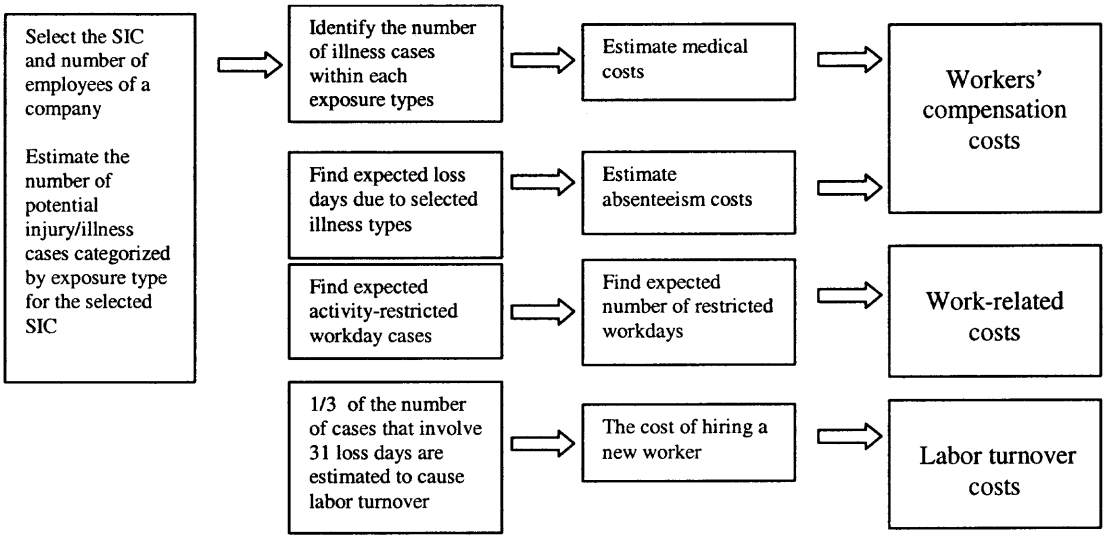

Figure 3.5 Flow diagram for estimating the potential costs due to MSDs problems

3.2 Ergonomic Intervention Compliance Cost

The cost of ergonomic intervention is obtained and modified from OSHA's recommendation of the former ergonomics standard. The modification is made mainly for estimating the amount of time managerial staff and workers spent on activities related to each program element. The costs of the elements for ergonomic interventions used in the database of the ergonomics justification framework are as follows:

A. Initialization/familiarization costs: There are two kinds of costs that OSHA recommended to be a part of the expenses while getting familiar with ergonomics programs to reduce work-related MSDs. One is the cost to review the standard in order to determine its applicability for the individual company as well as getting familiar with the standard. The other is the cost to investigate and evaluate each reported MSDs to determine if it is a covered MSDs as defined by the standard. The initialization cost and the parameters that drive such cost is summarized in Table 3.9.

Table 3.9 Initialization cost.

Provision	Level of staff	Time involved (hr)	Time per MSDs (hr)
Familiarization costs to review standard.	Safety/health Manager	10	N/A
Cost to investigate reported MSDs	Trained Manager	2	N/A
	Employee		0.3

Let I_{fc} is the initial familiarization costs

t_m is the manager's time spent

t_e is the employee's time spent

w_m is the manager's hourly wage

w_e is the employee's hourly wage

N_{msd} is the number of MSDs cases

N_e is the number of production employees

$$I_{fc} = (t_m * w_m) + N_e(t_e * w_e * N_{msd})$$

$$= 12\ w_m + 0.3\ N_e * w_e * N_{msd}$$

B. Basic ergonomics program costs: The basic ergonomics program consists of four elements:

B.1) Implement initial program: Management leadership and initial program implementation, including allocation of resources and assignment of program responsibilities.

B.2) Provide managerial training: Information and training for responsible managers.

B.3) Setup reporting system: Establishment of an employee reporting system.

B.4) Employee information: Provision of the information employees need in order to recognize the signs and symptoms of MSDs and MSDs hazards. Cost of a basic program is summarized in Table 3.10.

Table 3.10 The Basic Ergonomics Program Costs

Provision	Level of staff	Time involved (hr)	Time per employee (hr)
Cost to implement initial program	Trained manager	5	
Cost to provide managerial training	Manager	10	
Cost to setup reporting system	Trained manager	5	
Cost to provide employee information	Manager	5	1

BP is the cost of basic program

N_e is the number of production employees

w_m is the manager's hourly wage

t_m is the manager's time spent

$$
\begin{aligned}
BP &= (w_m * t_m) + (w_m * t_m) + (w_m * t_m) + (w_m * t_m) + (w_m * N_e) \\
&= w_m [\, 5 + 10 + 5 + 5 + N_e] \\
&= w_m [\, 25 + N_e]
\end{aligned}
$$

C. Full ergonomics program costs: A full ergonomics program must be implemented when an OSHA's record-able MSDs is reported even though a quick fix approach has been implemented.

C.1) Training for Managers and Employees: The framework estimates that 20 hours of one manager's time spent on training are needed to administer a full program implementation effectively. Such training managers are assumed to be capable of providing training to employees. Different size of companies may have different levels of personnel's to handle health and safety issues. Companies having safety and health people may need less training than others. Employee training is required for all employees working in problem jobs. The estimated training required by an employee to effectively handle a full program for his/her problematic jobs is 3 hours (understanding the impact, learn to identify and avoid stresses, etc). A group of 20 employees can be trained at one time while the manager is expected to spend 2 hours of preparation for each training session. Cost of training is indicated in Table 3.11.

Table 3.11 Full program training cost.

Provision	Level of staff	Time involved (hr)
Cost to provide managerial training	Manager with initial training	20
Cost to train employees	Employee	3
Cost to prepare training session for 20 workers or fewer	Manager	2

TR_{FP} is the full program training cost

TR_m is the cost to provide managerial training

TR_e is the cost to train employees

TR_{mp} is the cost of managers to prepare training sessions

t_m is the manager's time spent

t_{mp} is the manager's time spent preparing for a training session

t_e is the employee's time spent

w_m is the manager's hourly wage

w_e is the employee hourly wage

N_{tr} is the number of sessions (20 employee/sessions)

N_e is the number of employees

$$TR_{FP} = TR_m + (TR_e + TR_{mp})* N_{tr}$$

$$= (t_m * w_m) + [(t_e * w_e* N_e) + (t_{mp} * w_m)]* N_{tr}$$

$$= 20\ w_m + (3\ w_e* N_e + 2\ w_m)N_{tr}$$

C.2) *Job Hazard Analysis*: Job hazard analysis is the task of identifying the work activities and job conditions in the problem job, and later identify the risk-factors in that job which may be the cause, aggravate to contribute to covered MSDs. It is estimated that job hazard analysis using an ergonomic checklist will require 2 hours of managerial time per MSDs and 2 hours of employee time per MSDs. A fully detailed job hazard analysis may require more time for both managers and employees. Costs of job hazard analysis are categorized in Table 3.12.

Table 3.12 Job hazard analysis.

Provision	Level of staff	Time per MSDs (hr)
Cost of job hazard analysis (Ergo checklist)	Manager	2
	Employee	2
Cost of detailed job hazard analysis	Manager	10
	Employee	10

JHA_{FP} is the total cost of job hazard analysis in a full program

JHA_{ckl} is the cost of job hazard analysis using ergonomic checklist

JHA_{dt} is the cost of a detailed job hazard analysis

w_m is the manager's hourly wage

w_e is the employee's hourly wage

N_{msd} is the number of MSDs cases

$$JHA_{FP} = JHA_{ckl} \text{ or } JHA_{dt}$$

$$JHA_{ckl} = 2(w_m + w_e)N_{msd}$$

$$JHA_{dt} = 10(w_m + w_e)N_{msd}$$

C.3) *Evaluating Job Controls*: Once the manager or worker has identified the risk factors associated with job, the manager must determine how such risk factors can be controlled. Three levels of expertise are distinguished here to categorize the knowledge of the person involved in evaluating job controls. The first is by someone with relatively little background in ergonomics (level A). The second is by the trained ergonomics program manager (level B). The third is by outside ergonomic consultant (level C). Time related to evaluating job controls for each level of expertise is assigned in Table 3.13.

Table 3.13 Time related to evaluating job controls in hours.

Level of expertise	Worker time	Supervisor	Manager	Ergonomic consultant
A	1	2	0	0
B	4	8	8	0
C	8	16	16	16

$ConEv_A$ is the cost of evaluation job control case A

$ConEv_B$ is the cost of evaluation job control case B

$ConEv_C$ is the cost of evaluation job control case C

w_e is the employee's hourly wage

w_s is the supervisor's hourly wage

w_m is the manager's hourly wage

$ConEv_A = w_e + 2w_s$

$ConEv_B = 4w_e + 8w_s + 8w_m$

$ConEv_C = 8w_e + 16w_s + 16w_m + \$1,600$

C.4) MSD Management: Based on OSHA's recommendation, it is estimated that one hour of managerial time (ergonomist, ergo team leader, safety or health professional) is needed to conduct and manage each covered MSD.

Let MSD_{mgt} be the cost to provide MSD management

w_m be the manager's hourly wage

N_{msd} be the number of MSDs cases

$$MSD_{mgt} = w_m * N_{msd}$$

C.5) Record keeping: The record keeping is included the employee report of MSDs, episodes of persistent symptoms and response to such report, results of job analysis, hazard control records, quick fix records, ergonomics program valuation and MSD management records. OSHA assumes that it will take 0.25 hours of a supervisory worker to handle these various records for each covered MSD.

Rec is the cost to provide record keeping

w_s is the supervisor's hourly wage

$$Rec = 0.25\ w_s * N_{msd}$$

C.6) Program Evaluation: Workplaces with a full program are required to review such program periodically and at least every three years to ensure that they are in compliance with the OSHA standard. OSHA assumes that it will take 4 hours of management time to perform such review every year.

Let Ev be the cost to provide program evaluation

w_m be the manager hourly wage

$$Ev = 4w_m$$

D. The costs of job control: Based on the former ergonomics standard, employers are required to implement controls for the problematic jobs where employees experience a covered MSDs. The cost justification framework introduced in this research adopts OSHA's developed average costs for the job interventions for specific occupational groups that can translate into intervention costs based on SIC code. The steps to identify the costs of ergonomic controls are as follows:

D.1) Identify the occupational group: The study categorized occupation into 20 occupational groups which based on the similarity of the MSDs risk factors, the number of BLS lost workday cases, and the similarities of job interventions. Table 3.14 shows the group number and description of the occupational group.

Table 3.14 Occupational group description, occupational code and task related scenario.

Group Code	Description	Occupational code	Scenario code
1	Folding, packaging, and filling machine operators	765, 754	MH-22, MH-37, MH-47
2	Mixing, blending, separating, and clarifying machine operators	756, 757, 764	MH-12, MH-49
3	Painting machine operators	759	MFG-56, MFG-66
4	Machine operators, light	227, 228, 346, 347, 694, 695, 696, 699, 714, 726, 727, 728, 729, 733, 735, 736, 748, 773, 774	MFG-29, MFG-33, MFG-39, MFG-59, MH23, MH-24, MH-25
5	Lathing, boring, drilling, and rolling machine operators	616, 637, 639, 703, 704, 705, 707, 708, 709, 768	MFG-19, MH-52, MH-53
6	Molding, casting, and other fabricating machine operators	717, 719, 723, 725, 777, 779,	MFG-35, MFG-57
7	Freight, stock, and material handlers, hand	464, 876, 877, 883, 888, 889	MFG-42, MFG-48, MFG-54, MFG-65, MH-2, MH-4, MH-5, MH-8, MH-13, MH-15, MH-16, MH-17, MH-19, MH-20, MH-21, MH-28, MH-29, MH-31, MH-32, MH-43, MH-44, MH-46, MH-57, MH-58, MH-59, MH-64, MH-69, MH-72, MH-74, MH-79, MH-80
8	Forestry, fishing, and related occupations	473, 474, 475, 476, 477, 479, 483, 484, 485, 486, 487, 488, 489, 494, 495, 496, 498, 499	MH-68, OGI-13
9	Mechanics, installers, and repairers	503, 505, 506, 507, 508, 509, 514, 515, 516, 517, 518, 519, 523, 525, 526, 527, 529, 533, 534, 535, 539, 543, 544, 547, 548, 596, 865, 999	MFG-15, MFG-20, MH-1, MH-27, MH-35
10	Hand workers, light	628, 666, 666, 667, 674, 677, 678, 683, 684, 687, 864	MFG-2, MFG-11, MFG-12, MFG-13, MFG-23, MFG-24, MFG-27, MFG-28, MFG-32, MFG-34, MFG-36, MFG-40, MFG-41, MFG-43, MFG-45, MFG-61, MH-3, MH-11, MH-50, MH-51, MH-73, MH-77, OGI-11, OGI-18
11	Hand workers, heavy	634, 635, 636, 643, 644, 645, 646, 647, 649, 653, 654, 655, 656, 657, 658, 659, 668, 669, 675, 676, 679, 686, 688, 783, 784, 785, 786, 787, 789, 793, 795, 874, 885	MFG-1, MFG-4, MFG-6, MFG-7, MFG-8, MFG-9, MFG-17, MFG-25, MFG-30, MFG-44, MFG-46, MFG-47, MFG-51, MFG-55, MFG-63, MFG-64, MH-7, MH-14, MH-33, MH-39, MH-41, MH-65
12	Inspectors, graders, sorters, and weighers	368, 689, 693, 796, 797, 798, 799	MFG-10, MFG-14, MFG-16, MFG-21, MFG-26, MFG-31, MFG-49, MH-6, MH-9
13	Motor vehicle operators	497, 803, 804, 806, 808, 809, 813, 814, 823, 824, 825, 826, 828, 829, 833, 843, 844, 845, 848, 849, 853, 855, 856, 859, 875,	MFG-18, MFG-22, MH-34, OGI-12
14	Machine feeders and offbearers	878	MFG-3, MFG-52, MFG-53, MFG-60, MH-10, MH-75, MH-76, MH-82
15	Stock and inventory clerks	354, 355, 356, 357, 364, 365, 374	MH-30, MH-36, MH-62, MH-67
16	Sales counter occupations and cashiers	275, 276	MH-71, OGI-2, OGI-7
17	Food service occupations	433, 434, 435, 436, 438, 439, 443, 444	MH-54, MH-70, OGI-3, OGI-6, OGI-16
18	Textile and shoe machine operators	738, 739, 743, 744, 745, 747, 749	MFG-38, MFG-58, MFG-62, MH-55, MH-63
19	Printing machine operators	734, 737	MH-26, MH-81
20	Other machine operators	706, 713, 715, 724, 753, 755, 758, 763, 766, 769	MFG-5, MFG-50, MH-48, MH-78

D.2) Select intervention scenarios for the selected occupational group: Intervention scenarios are categorized for each occupational group based on OSHA's recommendation. The example of the description and cost for each scenario are shown in Table 3.15.

Table 3.15 Scenarios description and costs related (Examples).

Scenario code	SIC	Control type	Control description	Emp per control	Life of control	Control cost
MFG-1A	37	Engineering	Counter balance weight for tools	3	10	$700
MFG-1B	37	Engineering	Adjustable workstation fixture	3	10	$500
MFG-15	3721	Engineering	Pneumatic nut runner	2	3	$1,200
MFG-16	3711	Engineering	Redesign and semi-automatic test stand	2	10	$30,000
MFG-17	2821	Engineering	Pneumatic air wrench	2	-	$1,200
MFG-19	Manufacturing	Engineering	Hydraulic lift	8	7	$15,000

3.3 Database System for Ergonomic Cost/Benefit Estimation

The database was designed to estimate the costs related to MSDs problems and the investment needed for ergonomics program according to the methodology described earlier in this chapter. It would be a very tedious task to manually go through physical document, tables, and figures in order to identify the costs of MSDs and investment costs of an ergonomic intervention project for each particular company. A database is needed in order to establish the link or relationships among the collected data sources used for building queries to estimate the cost of MSDs problems and ergonomics programs expenditures. Furthermore, the BLS raw data are in either *PDF* or *Text* format, which cannot be used directly, data conversion from such format to Microsoft Excel or Access is needed. Microsoft Access 2000 was chosen for its simplicity, its ability to handle database information, and the efficiency in interfacing with other front-end programming language such as Visual Basic. The size of the database system is 40 Megabits with 150 tables and 100 queries that are designed to estimate the parameters needed for the economics valuation of an ergonomic project. The information that describes the field and records of the database tables and queries can be found in Appendix D. The database serve three purposes, one is to collect raw data from various sources; second is to capture the estimates, averages, and functions that was derived from data sources; third is for estimating the costs related to MSDs problems and ergonomics program costs.

The raw data extracted from BLS such as Table R8 described earlier in section 3.1 contains information about incidence rate grouped by over exertion and repetitive motion for each SIC during 1993 to 1997. The information for each year is kept in separate tables because the SIC reported each year are not exactly the same. Using the database entity relationships helps link the information with the same SIC code in each year. A similar problem existed in collecting raw data related to restricted activity cases because BLS (Table 2) has small variation of the reported SIC in each year of the data. Another set of raw data source is the data related to the parameters that triggers the costs of ergonomic project collected from OSHA former ergonomics standard. The main factors that determine ergonomics program element are wages of workers and time spent on different elements of ergonomics program. Although a default value can be used, such information is stored in tables so that changes can be made to the parameters needed for estimating each components of the ergonomics program according to a firm specifically: initialization, basic program, job analysis, etc.

Ergonomics program elements are grouped together based on their time to implement and project interdependencies in order to identify sequences of cash flow used for determining the value of the entire project. The initialization and basic program are grouped into Period 1, which is the start of an ergonomics program; the full ergonomics program starts with MSD management and record keeping process that are grouped as Period 2; Period 3 consist of training workers and job analysis activities either ergonomic checklist or detailed task analysis approach (Period 3A or 3B); Ergonomic control element is identified as Period 4, which can be calculated as minimum, average, and maximum ergonomic control costs based on the methodology described in the previous section; the evaluation of ergonomic control and yearly program evaluation are grouped together as the last component, Period 5.

The estimates of future potential MSDs problems due to the type of exposure, medical cost, and restricted work-activity coefficient are determined by either a five-year averages or regression functions as described in section 1. Such information is kept in database tables and query tables. For example, the *Exposure Rate Function Table* contains the intercept, slope, and the r-square that will estimate the potential injury cases that may occur for a specified number of years, while the medical expenses are estimated using the *Function_MedicalCost* table. These sets of table and queries can be modified or updated when new information arises in order to improve the r-square of the regression function or to have a more update average figures as well as the user preferences.

The estimated costs related to MSDs problems and the estimated investments needed for an ergonomics program are calculated by using groups of queries based on the methodology described earlier in section 3.1 and 3.2. The initial information that the database need in order to estimate such costs can be entered into the *CompanyInput* Table. The CompanyInput table required the user to enter SIC code in order to select the industry that the company is in; the number of employees in the company in order to estimate the proportion of potential MSD cases for the selected SIC; the estimated rate of labor turn over when a worker involve in days away from work over one month (1/3 is the study estimate); the percent reduction of workers performance during restricted work-activity is used in estimating work-related costs (1/3 is the study estimate); the PDP rate with known TDP is used for estimating indemnity payment, the number of production workers is used for estimating the cost of ergonomics program; and the occupation group code to identify scenario is selected for calculating ergonomic control costs. Users can adjust the input to the database according to the firm's preferences of the percent reduction of workers performance during restricted work-activity, the proportion of labor turn over, or the multiplying factor to TDP. For example, one company may find that PDP is five times of TDP (according to geographic region), which is different than the research suggested (2.174).

Figure 3.6 shows the framework diagram including the component needed in order to estimate the potential costs of MSDs and ergonomics program expenditures, so that project valuation can be determined using the net present value or the real options method. With a structured database it would be possible to integrate various data sources, establish relationships among data collected that can be used for valuing ergonomics program, while being able to improve mechanism for maintaining and updating in order to achieve the accuracy of the cost/benefit estimates.

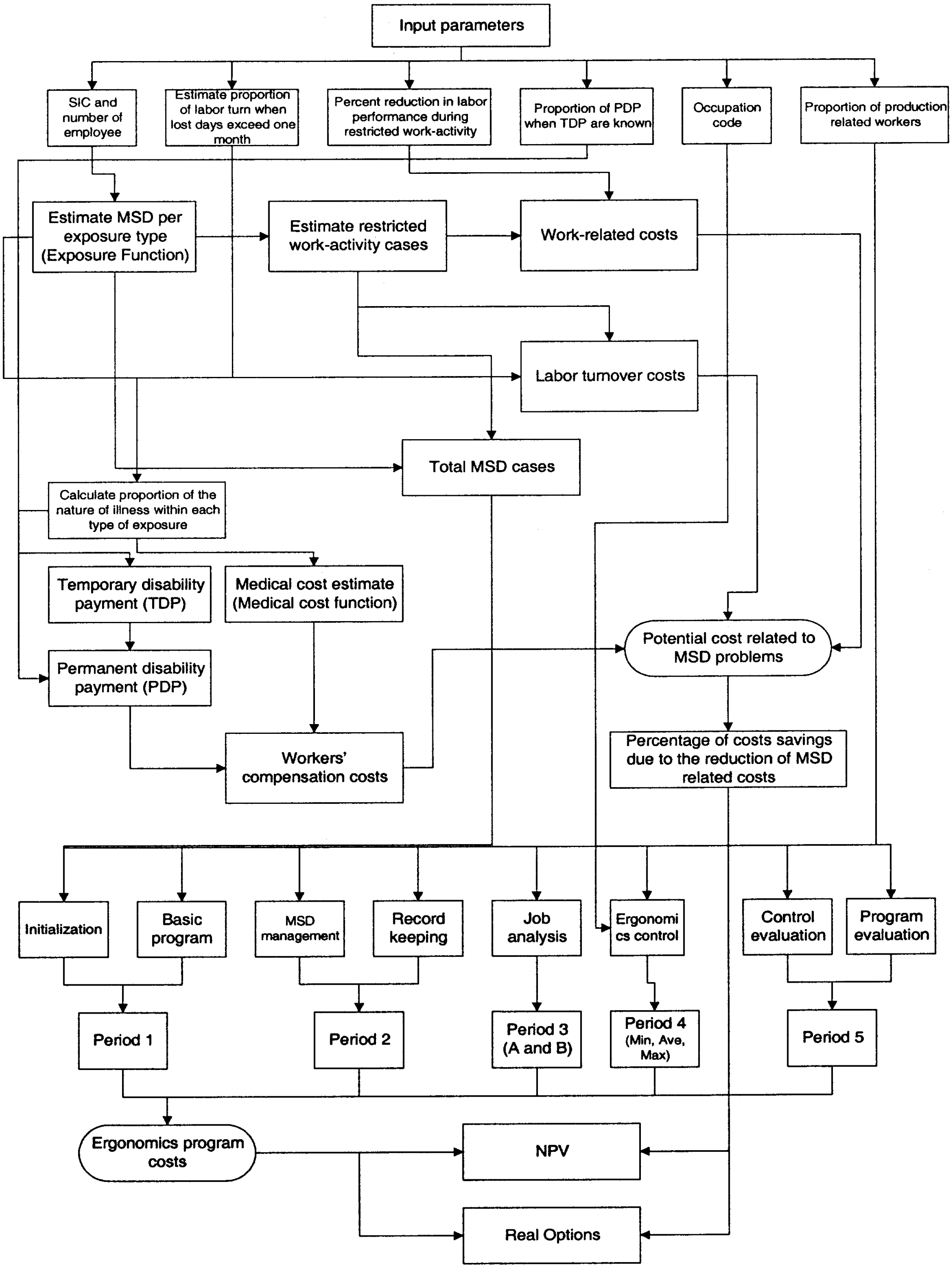

Figure 3.6 Flow diagram of the cost/benefit estimate of ergonomics program

CHAPTER 4

REAL OPTIONS APPLICATION IN ERGONOMIC INVESTMENT VALUATION

4.1 Real Options in Ergonomic Project Valuation

The real options method does not provide advantage over the DCF approach when the investment project is either incredibly valuable or the investment is a total loss, yet many investments falls between such two points *(Kulatilaka, 1999)*. There are investment characteristics where the real options method is suitable as a tool for quantifying the value of a project. Those characteristics are such as the uncertainty of future cash flow, the asymmetry in the probability distribution of NPV, and the dependencies among sequential or staged projects. One type of characteristics that motivates the use of real options is the uncertainty of the project's future cash flow. The uncertainty in the expected cash flow can gradually be resolved when new information arises, and as a result the expected cash flow may differ from originally expected. A lease to drill an undeveloped land (with potential oil reserve) enables management to wait and benefit from the resolution regarding uncertainties about oil prices *(Kulatilaka, 1999)*.

In telemedicine, the uncertainties in the rates of physician reimbursement for tele-consultation is often considered as one of the primary constraint to the wide spread use of telemedicine. Implementing telemedicine can be deferred until a later time. Such flexibility allows management to collect more information about the rate of reimbursement associated with telemedicine (*Cameron, 1998, p. 66-86)*. Other types of uncertainties that affect the costs/benefits of telemedicine systems include the usage volume of the system, the healthcare structure (managed care settings vs. fee for service), and the mix of service providers.

Examples of uncertainties related to ergonomics program are such as the technology advances that can identify specific dose/response more accurately, the market demand for a product may cause workers to produce more/high output and result in MSDs injuries, the differences in workers' physical that can result in the onset of MSDs, the fluctuation of medical costs, or workers' performance while on restricted work activities varies among workers. Such uncertainties affect the estimation of the costs related to MSDs, therefore, the cost reduction of MSDs problems that are gained through ergonomic projects are too affected. Ergonomic job analyses activities can provide a better understanding of MSDs problems in the workplace so that appropriate ergonomic controls can be implemented. The uncertainties surrounding the project's cash inflow, which is the benefits gained through ergonomic control, should be resolved as the job analyses activities complete.

Another characteristic for applying real options approach is when management has the flexibility to alter future actions. Management introduces an asymmetry or skewness in the probability distribution of NPV towards the positive side, because management can change the decision related to a project to meet their maximum return when future knowledge is collected. The uncertainties surrounding the project's cash flow reduce, therefore, the expected NPV distribution moves towards a more positive value than the original planned based on the more information gathered or resolved. Only when such ability exists, real options will be meaningful since if management does not have the ability to alter future project, there would not be skewness in the NPV's probability distribution. For example, telemedicine systems are highly scaleable in the sense that they can be expanded by adding spoke sites, consulting physicians, or equipment with greater capabilities while being able to terminate spoke sites if conditions turns unfavorable or even switch the use of the telemedicine system for non-clinical use. The flexibility to alter telemedicine project provides higher probability for the upside potential.

Sequential or staged investments with dependencies between prior and post completion of each stage can be viewed as another characteristics where the real options method provides additional information to an investment project. It is common for a firm to take on a pilot project before committing to a full-scale project. In such cases, the pilot project can be viewed as the rights for a firm to acquire the option to take on full-scale projects. Therefore, the pilot project's value should include the value of the option to take on future full-scale projects in addition to the initial project's NPV. A company may accept a negative NPV on the pilot project while seeing the possibility of a positive NPV on future dependent projects.

Such a situation can be seen typically in ergonomics programs for reducing MSDs problems where initial projects are taken in order to assess the ergonomics problems. As a result of such findings, ergonomic controls are implemented. The initial project creates an option for the firm to implement ergonomic project at the time of the completion of the initial project if the findings shows that MSDs exists significantly. Without the full knowledge of problematic jobs, it would be difficult to come up with appropriate and effective solutions. These initial projects often incur costs while the payoffs will seldom be generated until problems are solved through ergonomic controls.

Examples of the initial projects can be related to assessing the need for intervention such as job-task analysis, the study of the work environment, the motion and time study, data acquisition activities or feasibility studies. The amount of money associated with such activities can be seen as an initial investment. With the initial investment, one will be able to estimate the impact of poor ergonomics in the working environment and identify the possible cost savings or cost incurred from having poor ergonomics. Such cost savings can come from premium reduction of workers' compensation, reduction of absenteeism cost or reduction of labor turnover cost. By investing in additional ergonomic control, the company may be able to save costs or gain even more benefit.

Therefore, by understanding MSDs cost reduction through ergonomic practices, companies may be willing to further invest in engineering control, administrative control or personal protective equipment (PPE). New equipment, additional machinery, the adjustment of working conditions, designing new production layout facilities, or full automation may be implemented based on the findings of the initial projects. A firm has the option, but is not obligated, to implement ergonomic solutions as the firm prefers. The decision will be made based on the findings of the initial investments or the pilot project. Based on the knowledge of real options advantages, limitations, and characteristics, the study believes that such tool can provide additional information for ergonomic investment costs justification as well as expanding the research of ergonomic project valuation methodology.

The term real options valuation and contingent claim analysis are used interchangeably *(Teisberg, 1995).* Contingent claim analysis (CCA) is a technique for determining the price of a stock whose payoff depends upon the price of other stock. The value of the ability to invest is not the same as the value of the physical investments but is rather derived based on the possible expected range of return from the future physical investments. The major advantage of using this approach as opposed to the decision tree method is that it eliminates the need to estimate the actual probabilities of future project values. Furthermore, the method uses a risk-free rather than a risk-adjusted discount rate (see page 29 Chapter 2). Uncertainty surrounding the project's outcome that leads to the range of the project's return in the future can be estimated on the basis of its volatility instead of having to assign probability in every future node of a decision tree.

Let task analysis activities for a manufacturing facility to investigate MSDs problems be completed at time 'n'. At time 'n' the study identifies that there are MSDs problems and it is possible to solve such a problem through ergonomic solutions which costs 'X' dollars. Assume that the ergonomic solution cannot directly prevent MSDs problems until the task analysis is completed. The company can implement ergonomic solution when the task analysis finds the need otherwise continue to investigate and train workers to identify MSDs hazards. In other words, the company has the option to acquire ergonomic solution (but not obligated) if MSDs problems doe not exists. The benefits of ergonomic solution are the prevention of MSDs injuries. Such preventive measures can result in less injury cases that can be translated into lower medical expenses, lower absenteeism costs, and lower turnover costs.

The method used for quantifying the value of an option to acquire ergonomic solution is based on factors similar to valuing financial options. Those factors are the value of the underlying asset 'A' (cash inflow or potential costs savings), the investment costs for the ergonomic solutions 'X', the risk of owning the project 'r' (measured by risk-adjusted rate), and the time it takes to complete task analysis phase '*n*'. Let the present value of the expected cash flow of the benefits of implementing ergonomic solutions at time n is *A*, Assuming that the company has a fixed time horizon (*n*), at the end it has to make the final decision on whether or not to implement such ergonomic solutions (the time between the initial investigation and the implementation of an ergonomic solution) and the total investments needed for such ergonomic solutions is *X*. The decision to invest in such ergonomic solutions using NPV as decision criteria is described as follows:

If $A > X^{(-r)}$, The project has a positive NPV

$A < X^{(-r)}$, The project has a negative NPV

One can view that the pay-off diagram relationship represented in Figure 4.1 is that of a call option. The underlying asset is the present value of the project expected cash flow 'A'; the strike price at time 'n' is the investment needed 'X'; the life of the option is the period for which the company has rights to implement ergonomic project by implementing task analyses activities. The time it takes to complete task analyses can be viewed as the life of the option to acquire ergonomic solution since at the completion of such activity the knowledge of MSDs injuries are known and decisions must be made to solve such problems through ergonomic solutions or continued with other analyses activities or training. At the fixed time horizon (n), ergonomic solutions will be implemented if the present value of the expected cash flow at time (n) exceeds the costs of the ergonomic solutions.

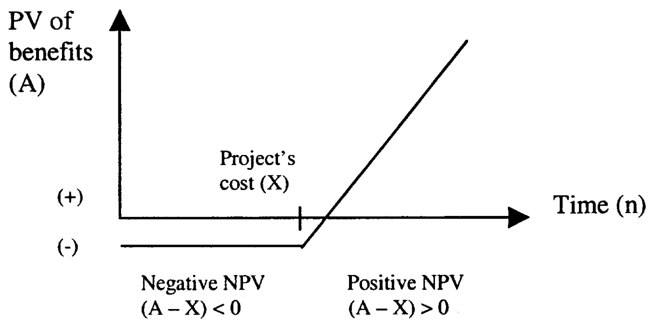

Figure 4.1 Ergonomic project pay-off diagram

The total value (expanded NPV) of the ergonomic intervention is the net present value of the initial ergonomics problems investigation plus the value of the option to further implement ergonomic solutions, illustrated in equation 4.1.

Expanded (strategic) NPV = static (passive) NPV of expected cash flows

+ value of options from active management *(Trigeorgis, 1993)*. ....(4.1)

The input needed for real options valuation applicable to ergonomic investments can be summarized as follows:

- *The value and variance of the underlying asset:* The value of the underlying asset arises from the expected cost savings generated from future ergonomic solution. Such monetary benefits can come from the reduction in workers' compensation costs, reduction in absenteeism costs and reduction in labor turnover expenses. These cost savings can occur if the ergonomic solutions reduce the MSDs incidence rate. The variability of the estimated potential benefits can be estimated using the volatility of the stock price for a particular industry a firm is in (a suggested approach to estimate the variance of the underlying asset, *Kulatilaka 1998, Damodaran 1997).* Another approach is to use the historical data to estimate the variability of the incidence rate incurred for a particular industry type or occupational type.

- *Exercised price:* The ergonomic solution costs are equivalent to an exercised price of a call option. The assumption is that this cost remains relatively stable.
- *Expiration of the option:* The time required for the task analysis activities to be completed is one example for determining the options expiration time. In most cases, there is no specific time horizon by which a firm has to implement an ergonomic solution. Even though the time horizon is an open-ended option, some estimate from previous experience, ergonomic consultant or based on literature can be applicable. Sensitivity analysis can be used to identify the effects of utilizing different time horizons. In some circumstances, outside contractors may provide the time to complete a project.
- *The risk-free rate:* The return of an investment with a risk-free rate is guaranteed, since an ergonomic solution will not be invested until some time in the future, it is the same as putting the money into risk-less bonds such as short-term government securities.

A diagram of the mapping parameters needed to value a call option against the input identified through ergonomic intervention characteristics is shown in Figure 4.2. Possible real options that may be embedded in ergonomic projects is introduced in Table 4.1.

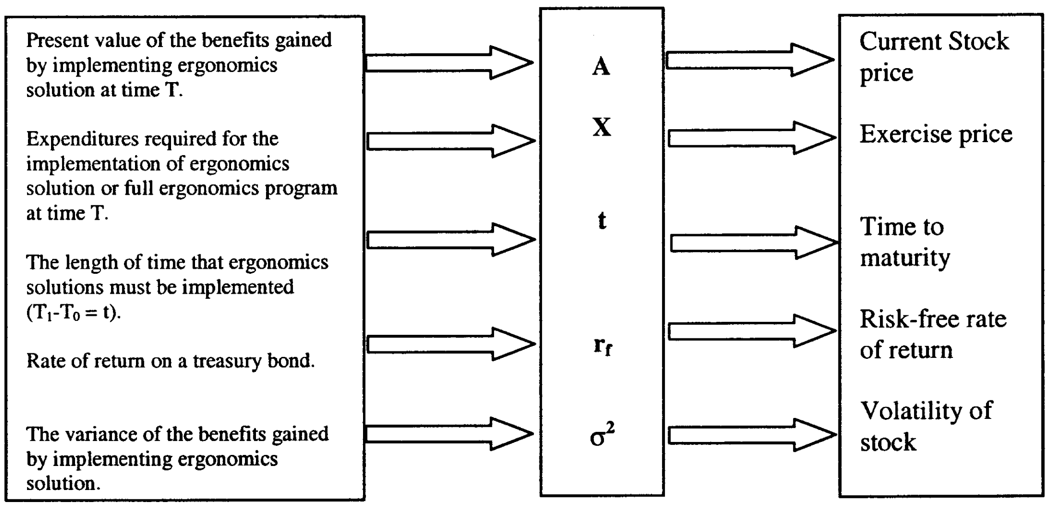

Figure 4.2 Mapping ergonomic project valuation to a call option

Table 4.1 Possible real options in ergonomic project

Types of real options	Description
Option to acquire ergonomic solutions	Task analysis activities creates the option to implement ergonomic solution at the of the job analysis activities.
Option to accelerate job analyses activities	There is an option to speed up job analyses activities in order to gain additional benefits from early ergonomic intervention.
Option to expand ergonomic checklist to a detailed task analyses	There exists an option to expand ergonomic checklist to a detailed task analysis when result from ergonomic checklist provide further need for a detail task analyses.
Option to defer full automation	A full automation approach in solving MSDs problem can be deferred until other ergonomic control proved to be inefficient in eliminating MSDs problems.
Option to reduce the cost of ergonomic evaluation activities	The costs of evaluation of ergonomic control may be reduced by using internal resources to evaluate ergonomic control as opposed to outside consultant .
Option to replace MSDs injured workers with workers without MSDs injury	The option to replace workers with MSDs problems can be created by implementing cross-training, so that when MSDs problem arises the cross-trained employee can replace the MSDs injured workers.

4.2 Advantage of Real Option Over DTA and DCF Method

Real options avoid the limitation of both the decision tree analysis (DTA) and the net present value (NPV). The DTA method described in section 2.5 has its advantages when dealing with project valuation where the outcome of future stages affect the project's current value. In the DTA method, probability distributions are used for identifying the risk involved where a constant risk-adjusted discount rate is assigned for each future stage of investments. By folding back the expected value along the decision tree, the net present value of the expected cash flow is derived by using the constant risk-adjusted discount rate. However, as time moves forward the knowledge of future outcome increases, as a result the uncertainty of cash flow involved should be reduced. Therefore, the risk-adjusted discount rate should be adjusted appropriately according to the future knowledge of the risk involved. The limitation of the decision tree analysis in dealing with the determination of discount rate used can be critical since physical projects are competing with other investments as well as investment in financial markets. The discount rate selected for the project's valuation must be adjusted according to the risk involved, although a risk-free rate may be used, still the probability distribution must be estimated for each future event along the decision tree path.

Contingent claim analysis or options approach identifies the value of an opportunity to invest instead of pricing the value of a project directly. By identifying the opportunity to invest as options rather than seeking the value of the project, eliminates the cumbersome of having to estimate the probability distribution for future outcome as well as the appropriate risk-adjusted discount rate. The following discussion describes the reasoning why the estimation of future outcome probabilities is not needed for calculating the value of an opportunity to invest. Rather, a risk-neutral probability and the risk-free rate are used as parameters to measure the value of an opportunity to invest.

Suppose that a firm plans to implement an ergonomic solution in two stages, first the pilot project, followed by a full-scale project ($8,000) a year later if the pilot project is successful. Let the NPV of the pilot project be $1,000. The full-scale implementation is expected to save a combined medical costs, absenteeism costs and labor turnover costs, measures in terms of present value, of $7,500. Assume that at the end of the pilot project (one year from now) more information is available and the estimated savings from the full-scale project will vary according to some probability distribution. The probability of achieving cost savings of $10,000 is 0.8 and 0.2 being $5,000 respectively. Let "V" be the expected value of the full-scale project. Such savings from the full-scale project can be translated into a rate of return of 20%, which is calculated as follows [(0.8*$10,000 + 0.2*$5,000)/$7,500]-1. Since the project is competing against an investment in financial markets. Using the same analogy as the NPV method, assuming that there exists a stock that behaves similar to the kind of investment described earlier where one year from now the stock would be priced 10,000/7,500 times of the original value or 5,000/7,500 times of the original value, with the same risk (0.8 and 0.2 probabilities) as the full-scale project. Let "S" be the price movement of such stock where the current price is at $37.5 and one year from now it will be either $50 (prob. = 0.8) or $25 (prob. = 0.2). Based on such an assumption, the stock would have an expected rate of return of 20%, which is calculated as follows [(0.8*$50+0.2*$25)/$37.5]-1, replicating an exact 20% return as the investment in the full-scale project earlier.

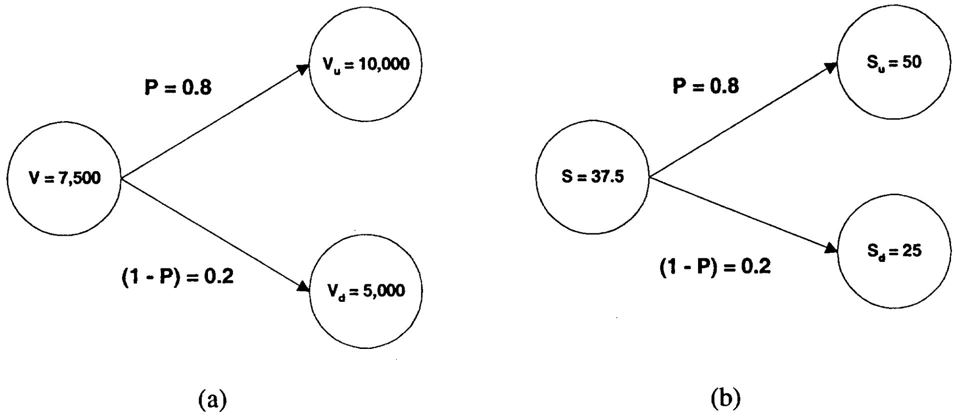

Figure 4.3 Value diagram: a) Possible future benefits from the full-scale project. b) The price movement of the twin-security that has similar risk characteristics as the benefits of the full-scale project.

Contingent claim analysis or options approach measures the value of the opportunity or the ability to invest in a full-scale project one year from now, by perceiving that one would further invest as planned only if future outcome turns to its advantage. Otherwise, not to invest in future project. Let such an option to invest has a value equal to "E" and it is perfectly correlated with the possible savings "V" or the price of stock "S". Following a standard option pricing hedging strategy, it is possible to construct a portfolio consisting of "n" shares of "S" partly financed by borrowing an amount "B" at rate r. Such portfolio shown in Figure 4.4 can be chosen so that it replicates the opportunity or the ability to implement a full-scale project *(Trigeorgis, 1987)*. The number of shares "n" and amount of "B" borrowed can be solved and the result will be, $n = (E_u - E_d) / (S_u - S_d)$, $B = (E_u S_d - E_d S_u)(1+r)^{-1} / (S_u - S_d)$.

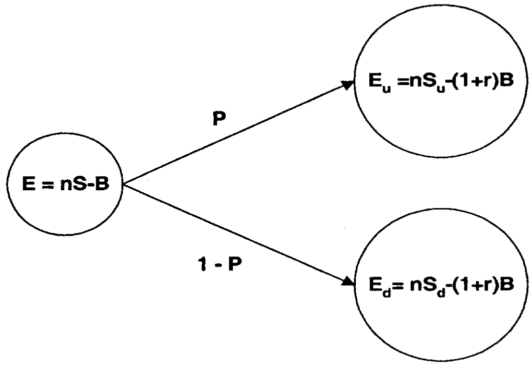

Figure 4.4 Portfolio strategy

So if at time 0 (present time) $E = nS - B$

Then based on "n" and "B",

$$E = \frac{(E_u - E_d)}{(S_u - S_d)} S - \frac{(E_u S_d - E_d S_u)(1+r)^{-1}}{(S_u - S_d)}$$

$$E = \frac{E_u S - E_d S - E_u S_d (1+r)^{-1} + E_d S_u (1+r)^{-1}}{(S_u - S_d)}$$

Rearrange

$$E = \frac{E_u \{S - S_d (1+r)^{-1}\} + E_d \{S_u (1+r)^{-1} - S\}}{(S_u - S_d)}$$

At year one

$$(1+r)E = E_u \frac{\{(1+r)S_u - S_d\}}{(S_u - S_d)} + E_d \frac{\{(S_u - S(1+r)\}}{(S_u - S_d)}$$

$$E = [qE_u + (1-q)E_d] / (1+r)$$

Where

$$q = \frac{\{(1+r)S_u - S_d\}}{(S_u - S_d)}; \quad (1-q) = \frac{\{(S_u - S(1+r)\}}{(S_u - S_d)}$$

So

$$q = \frac{\{(1+0.05) * 37.5 - 25\}}{(50 - 25)} = 0.575$$

And $(1-q) = 0.425$

From the above illustration, it can observe that the value of the opportunity to invest in the full-scale project (E) does not involve the actual probability p, but rather the probability q. The probability q is the weighted factor for the possible future cost savings where often referred as the risk-neutral probability *(Tiesberg, 1995).* Such risk-neutral probability allows the expected value to be discounted at the risk-free rate of 5% as opposed to the risk-adjusted rate of 20%. By applying the risk-neutral probability q of 0.575 and risk-free rate 5%, obtained the value of the option to invest in the full-scale project (E_{opt}) to be $7,500, which is the same as the value of the full-scale project (E_{trad}) using traditional DCF with actual probability p of 80% at the risk-adjusted discount rate of 20%.

$$E_{opt} = [qE_u + (1-q)E_d] / (1+r) = [0.575*\$10,000 + 0.425*\$5,000] / (1.05) = \$7,500$$

$$E_{trad} = [pE_u + (1-p)E_d] / (1+r) = [0.8*\$10,000 + 0.2*\$5,000] / (1.2) = \$7,500$$

The point here is that, instead of discounting the expected future value using the actual probabilities 0.8 at the risk-adjusted rate of 20%, options valuation approach equivalently discounts expected future values using risk-neutral probabilities 0.575 at the risk-less rate of 5%. Such approach eliminates the guessing of the discount factor needed for folding back the future value of the project to its present value. Also, there is no need for management to layout the estimated probability for the future expected project value. Instead, the uncertainty in future cash flow generated from the full-scale project is represented by the variance of the expected cash flow that determines the risk-neutral probability.

Recall that the NPV of the pilot project be $1,000 ($NPV_{pilot}$) and the full-scale project that will be implemented a year later be $8,000. The full-scale project is expected to generate the above savings of either $10,000 or $5,000. The real options approach assumes that management has the ability to determine the decision to implement the full-scale project if the pilot project is a success and receives the benefits generated, or not to implement the full-scale project when the pilot project fails and receives no benefits. Therefore, using the option method, the value of the option (E_{Option}) to implement the full-scale project in order to receive cost savings of either $2,000 or $0 project is $1,150, which makes the whole project (pilot plus full-scale, ENPV) value to be $2,150.

$$E_{Option} = [qE_u + (1-q)E_d] / (1+r) = [0.575*\$2,000 + 0.425*\$0] / (1.05)$$

$$= \$1,150$$

$$ENPV = E_{Option} + NPV_{pilot}$$

$$= \$1,150 + \$1,000$$

$$= \$2,150$$

Using the DCF approach the value of the full-scale project (NPV_{full}) can be over-estimated to be $2,083 and lead to a total project value of $3,083 illustrated as follow.

$$NPV_{full} = \{[0.8*\$10,000 + 0.2*\$5,000] - \$8,000\}/1.2 = \$2,083$$

$$NPV = NPV_{pilot} + NPV_{full}$$

$$= \$1,000 + \$2,083$$

$$= \$3,083$$

Based on the DCF analysis one would ask whether an investor would be willing to pay $2,083 for the full-scale project. Based on the portfolio analogy, the value of the opportunity to invest in the full-scale project in order to receive benefits of $2,000 or $0 is $1,150. Such investment can be replicated by a portfolio of securities consisting of 80 shares to buy and $1,905 amount of money to borrow.

$$n = (E_u - E_d) / (S_u - S_d) = (\$2{,}000 - 0)/(50\text{-}25)$$
$$= 80 \text{ shares of stock}$$

$$B = (E_u S_d - E_d S_u)(1+r)^{-1} / (S_u - S_d) = (\$2{,}000*25\text{-}0*\$2{,}000)*(1.05)^{-1}/(50\text{-}25)$$
$$= \$1{,}905$$

By buying the number of shares and borrowing the amount of money identified in the above description, investment in the next year will be worth either $2,000 or $0, which equals the difference between the upside benefits and the full-scale implementation costs ($10,000 - $8,000) or $0.

$$E_u = nS - (1+r)B = 80*50 - (1.05)*\$1{,}905$$
$$= \$2{,}000$$
$$E_d = nS - (1+r)B = 80*25 - (1.05)*\$1{,}905$$
$$= \$0$$

Using the DCF method, the full-scale project is worth \$2,083. So why would an investor spend \$2,083 for the same investment return (\$2,000 or \$0) with the same risk characteristics that is worth only \$1,150? In order to avoid the possibility of risk-less arbitrage profit opportunities, the value of the opportunity to invest in the full-scale should be \$1,150 as given by the options approach.

4.3 Case Study

In order to demonstrate the application of real options in the ergonomics program valuation, a study done by *Lanoie and Tavenas (1996)* was selected as a case since it provided detailed information of cost and benefit data for a participatory ergonomics. Participatory ergonomics is an innovative field requiring that the main principles of ergonomics be taught to workers so that, by drawing on their own experience, they can suggest their own solutions to work-related ergonomics problems.

4.3.1 Description of The Case

A study was done to evaluate participatory ergonomics for a warehouse that consisted of mainly putting products together. The manual material handling involved regular handling of boxes containing bottles of wine and spirits. Boxes were circulated in the warehouse on wooden pallets with a fork truck and pallet trucks. At the end of 1980, back disorder cases were frequent found among workers and it was decided that an ergonomics program would be needed to reduce back injuries. In fall of 1989 a working committee was put together to implement the program.

In the beginning of 1990, members of the group received training on principles of participatory ergonomics. The group met once a week to discuss safety problems and their solutions. The costs (present value in 1989) related to the committee member training, the costs of meetings, and cost of the time spent on activities related to the program can be found in Figure 4.5. By the end of 1990, six major problems were identified and the activities to solve those problems were recommended by the ergonomic committee:

1. Task related to installing heavy wooden pallets on a pallet truck involved movements that were painful and dangerous to worker's back. A recommendation was made to install an automatic pallet distributor to improve workers' task and speed up operations. The present value in 1991 of the total expenses related to the automatic pallet installation, training, maintenance and extra labor are in Figure 4.5.
2. The need to improve workers' posture and reduce workers' energy expenditures. Activities related to the design of a new pallet truck to better adapt to the size of workers and to improve workers' posture was recommended. Such redesigned pallet trucks were implemented in 1991.
3. The problem of boxes stuck together on pallets created problems in material handling. Several solutions were implemented to solve these problems such as changing the glue type or changing the type of cardboard used for the boxes. The added cost was the purchase of magnet labels to identify the problematic piles. The problem was finally solved in 1991.

4. Manual wrapping of pallets made workers feel dizzy, and, when the pile on the pallet was high, caused injuries to workers' backs. Instead of manually wrapping boxes an automatic wrapper was recommended to keep boxes stable on the pallet. The automatic wrapper was implemented in 1993 included activities are maintenance of the automatic wrapper and training of workers to use it.
5. Truck operators often suffered back-related problems because of their poorly designed truck seats. Two truck seats were needed to prevent back-related problems. The truck seats were implemented in 1991.
6. The handling of boxes exposes risks related to the hand. A recommendation for new gloves designed to facilitate handling of boxes was made. Workers then were equipped with such gloves starting from 1991.

The costs related to each recommended work activity in present value at each year can be found in Figure 4.5. The benefits estimated from the reduction of back injuries are also shown in Figure 4.5. Results from the case study indicated that ergonomic solutions were successful to prevent many back injuries *(Lanoie and Tavenas, 1996).* The direct/indirect cost savings as a result of injury reduction are computed at different discount rates (see Table 4.2). The derived net present value of the project was -$7,982.64 at a discount rate of 11.5%. Sensitivity analyses for various discount rates can be seen in Table 4.3.

From the description of the case, it can be assumed that if management were to decide, based on a 20% expected return on investment, the project would yield a negative NPV of -$29,192.42. The internal rate of return (IRR), the discount rate that equalizes cash inflow and outflow, was calculated to be 4.89%. Based on such an analysis, it would not look promising from a financial point of view if one were to determine whether to implement such a project at the time of 1989.

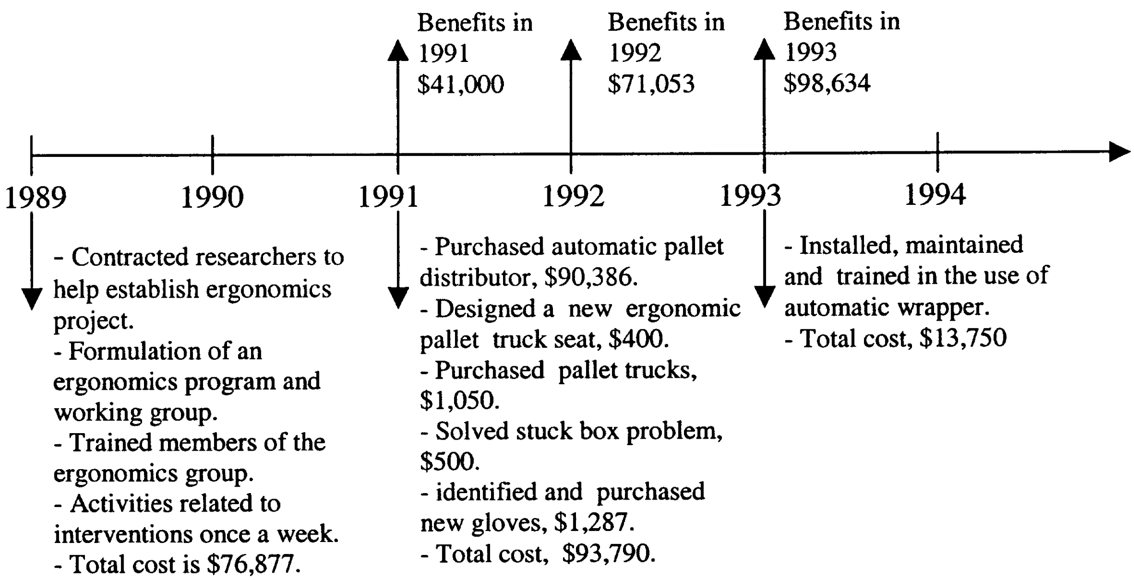

Figure 4.5 Cash flow and ergonomic intervention activities. The present value of the related cost each year are based on the study reported by Lanoie and Tavenas. The benefits generated from respective activities are derived in terms of present value for each time period (1991, 1992, and 1993).

Table 4.2 Present value (PV) of the project's estimated savings from the reduction in back injuries each year at different discount rate (A derived table based on *Lanoie and Tavenas, 1996)*.

PV of benefits	Discount rates (%)			
for each year	5	11.5	15	20
1991	37,189	32,980	31,003	28,473
1992	61,378	55,040	46,718	41,118
1993	81,146	68,526	56,394	47,567
Total	179,714	156,546	134,116	117,158

Table 4.3 The costs, total benefits and the Net Present Value of the planned ergonomic project at different discount rates (The values are derived from a study conducted by *Lanoie and Tavenas, 1996*).

	Discount rates (%)			
	5	11.5	15	20
Costs	180,015	164,529	157,351	146,351
Benefits	179,714	156,547	134,116	117,158
NPV	301	-7,982	-23,235	-29,192

4.3.2 Analysis of Participatory Ergonomics Program Using an Options Approach

From the implementation descriptions, it can be seen that the six recommended ergonomic activities can be grouped into three main parts according to the time of implementation: the initial stage costs, the problem solving stage, and the fine-tuning stage. The costs associated with each stage are shown in Figure 4.5. The initial stage in 1989 consisted of ergonomic background training for committee members and activities devoted to generate ideas for solving back-related problems. Ergonomic activities for the problem solving stage (stage 1) in 1991 consisted of implementing the automatic pallet distribution systems, designing and purchasing new gloves, purchasing a new pallet truck, and the provision of stuck box and truck seat. The fine-tuning stage (stage 2) in 1993 consisted of implementing the automatic wrapper, and training for and maintenance of such equipment. It is reasonable to imagine that in the year 1989, the only investment commitment was for the initial project. It can assume that it would be difficult to assess the costs and benefits of each of the six recommended ergonomic projects in the early stage of the project. Only after the implementation of the initial stage will a better picture of the benefits of ergonomic projects investments be realized.

The benefits gained from implementing stage 1 in 1991 or stage 2 in 1993 should have been known after 1989. It is possible to assume that management can estimate probability distribution to the benefits gained from implementing the subsequent stage 1 and stage 2. The real options approach suggests that such staged investment with unclear knowledge of future cash flow should not be evaluated based purely on the project's NPV. Assuming that the capital commitment in 1989 was only for the initial stage, the financial value of the subsequent stage 1 and 2 therefore, should be the value to acquire stage 1 and 2 as opposed to the value of the projects themselves. The value to acquire stage 1 and 2 is like a derivative asset where such value is derived based on the future value of stage 1 and 2. Based on real options analogy, the total value of the planned participatory ergonomics program is the present value of the initial stage plus the value of the option to acquire stage 1 and stage 2.

The calculation of finding the value of the option to acquire stage 1 and 2 used the binomial lattice method shown in Appendix B. The maturity periods are 2 years for the option to implement stage 1 and 4 years for the option to implement stage 2. This study is assumed that the underlying asset (benefits of ergonomic intervention) based on the total present value (discounted back to 1989) of the estimated expected cash inflow of \$156,547 (Table 4.2) is broken down into present value of \$151,547 generated from stage 1 and \$5,000 from stage 2. The benefits estimated are based on 1991-1993 figures. Since stage 2 is implemented in 1993, the \$5,000 used as stage 2 benefits is the smaller amount. The real options approach assumes that there exists an uncertainty in the estimated expected cash inflow that can be translated into the percentage of cash inflow variability or variance.

An estimated variability in the cash inflow (underlying asset) is assumed to be equal to 40% (the variance of the particular industry of the firm). A risk-free rate equal to 5.5% is used instead of the risk-adjusted rate of 11.5% since the objective is to price the option to acquire future projects as opposed to the project itself. The risk-free rate is the interest rate on which bonds of all maturities can be bought or sold in any amount. The reason that the risk-free rate is used in valuing options is the need to avoid guessing the future interest rate. The binomial method will correctly value the option to acquire projects based on the risk-free rate by using a risk-neutral transition probability described in section 4.2.

Parameters used in the calculation of the expansion option are shown in Table 4.4 The total value (expanded NPV) based on the equation (4.1, page 76) of the project can be found in Table 4.5 in column 5. The NPV of the initial investment (-$76,877) consisted of the costs of training and the costs of activities related to intervention, assuming that such return will generate only if ergonomic solutions are implemented. When we look at the initial phase as an option to further implement ergonomic solutions, the value of the initial investment can be significant. The reason is that such initial investment provides the ability to further develop ergonomic solutions. This ability to implement ergonomic solutions has a value, and that value can be measured using an options valuation approach.

Table 4.4 Parameters needed for option valuation

Stage	Present value				
	Underlying asset (A)	Investment costs (X)	Time to implement (n) years	Variability (σ)	Risk-free rate
1	$151,546	$93,789	2	0.4	5.5%
2	$5,000	$13,749	4	0.4	5.5%

Table 4.5 Real Options and NPV comparison at Variance = 0.4 and i = 11.5%

Criteria	Present value				
	NPV (1)	NPV Initial Project (2)	Stage1 Opt-V (3)	Stage2 Opt-V (4)	Expanded NPV (5)
Stage 1 only	-$7,982	-$76,876	$78,848	N/A	1,971
Both stages	($16,367)	($46,520)	$14,410	$20,347	($11,761)

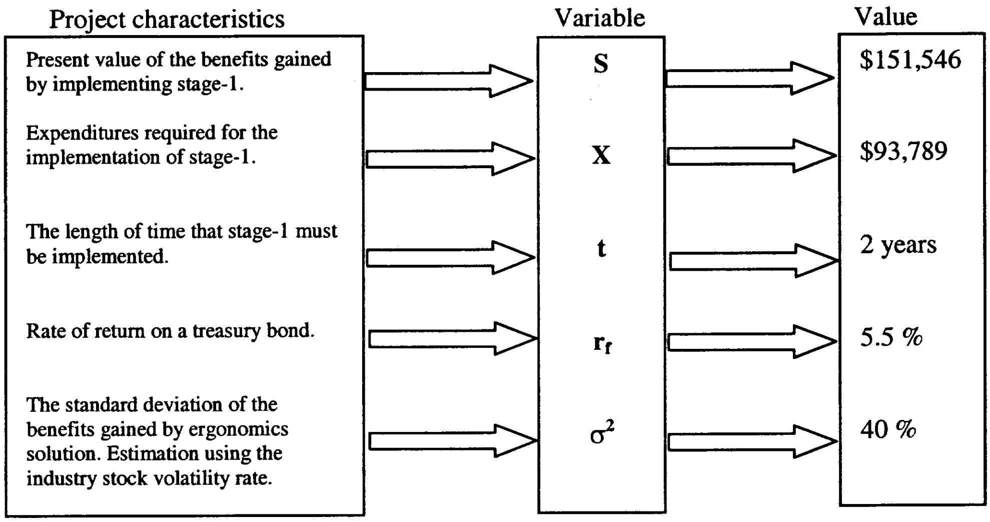

Figure 4.6 Valuing the opportunity to invest in Stage 1 as a call option

Analysis indicates that by adding the value of the option to acquire the ergonomic solution stage 1 ($78,848) into the initial investment ($76,877) increases the value of the initial investment from a NPV of -$7,983 to $1,971 (Table 4.5 column 5). The project will give an internal rate of return (IRR) of 10.08 percent as compared to 8.96 percent using only the net present value method. When the option to acquire stage 2 is included, the expanded NPV results in negative NPV. The implementation of stage 2 should not be a factor to turn down the implementation of the initial investment because the overall expanded NPV returns negative value. Because the implementation time for stage 2 is 4 years from 1989, future uncertainty related to the estimated benefits may be resolved, and as a result affects management commitment on stage 2.

A sensitivity analysis on the project can be done to illustrate the changes in the value of the NPV by varying different volatility estimates shown in Table 4.6. In the case the decisions to invest were determined based on the benefit/cost ratio, it would also have been discouraging because the ratio is below one for implementing the initial project plus stage 1, as well as the initial project plus stage 1 and stage 2.

Table 4.6 Sensitivity analysis for different rates of variability in the estimated benefits

Ergonomic projects	Volatility	Option value ($)	Expanded NPV ($)	Benefit/ Cost Ratio	IRR	IRR-Opt
Initial + Stage 1	0.3	76,008	-870	0.62	8.96	10.08
	0.4	78,848	1,971			
	0.5	82,280	5,403			
Initial + Stage 1 + Stage 2	0.3	76,190	-687	0.85	4.89	8.04
	0.4	79,347	2,470			
	0.5	83,165	6,288			

CHAPTER 5

RESULTS

The study intend to identify the costs of MSDs problems and investments associated with ergonomics program and illustrate methods for ergonomics project valuation using the real options approach. First, the potential MSDs related costs over a six-year time frame are generated from the database. Second, ergonomic investments needed in order to achieve the OSHA former ergonomics standard are estimated. Benefits from an ergonomics program are the potential cost savings as a result of the reduction in MSDs related costs. The percentage reduction of MSDs related cots are determined according to ergonomics program effective rate. Third, project valuation using the net present value method and the real-options method are illustrated. The following industry groups have been selected for the cost-benefit estimation of ergonomic intervention to reduce MSDs injuries and illnesses. The selected fifteen SIC groups are among the top industries with high MSDs injuries during 1994 – 1998 *(BLS website)*. Ranking of MSDs injuries for the year in each particular SIC is shown in Table 5.1.

The study needs to estimate the number of employee and production workers for the selected industries. The number of employees and the proportion of production workers are estimated using the median number of employees for a particular SIC. Table 5.2 shows the number of employees and the estimated production workers for the selected industry. Such data were derived based on the 1997 Economic Census *(U.S. Census Bureau, 2000)*. Based on the number of employee in each SIC, the expected number of MSDs cases with days away from work over a six-year time frame is estimated.

Table 5.1 The selected SIC with high MSDs injuries during 1994-1998 (adopted from BLS website).

Selected industries with high MSDs injuries	SIC	MSDs ranking for each year				
		98	97	96	95	94
1. Meat packing plants	2011	1	1	1	1	1
2. Motor vehicle and car bodies	3711	2	2	3	2	3
3. Poultry slaughtering and processes	2015	3	3	5	4	4
4. Men's and boy's trousers and slacks	2325	1	5	7	10	10
5. Men's footwear, except athletic	3143	5	10	n/a	n/a	22
6. Household laundry equipment	3633	1	n/a	4	5	18
7. Household refrigerators and freezers	3632	8	9	8	8	8
8. Automotive stampings	3465	10	19	13	12	12
9. Engine electrical equipment	3694	11	11	10	9	8
10. Motor vehicle parts and accessories	3714	12	15	11	18	19
11. Household appliances.	3639	15	13	16	15	n/a
12. Sausages and other prepared meats	2013	17	16	17	7	11
13. Motorcycles, bicycles, and parts	375	19	6	20	11	6
14. Knit underwear mills	2254	n/a	4	2	3	2
15. Men's and boy's clothing, except trousers and slacks	2326	n/a	12	12	14	15

Table 5.2 The estimated number of employees and production workers for the selected SIC (Median is the median number of employees for all establishments; Mean is the average number of employees for the fourth quartile of firms in the selected SIC).

Selected industries with high MSDs injuries	SIC	Data derived from 1997 Economic Census		
		Number of employee (Median/Mean)	Proportion of production workers	Number of production workers (Median/Mean)
1. Meat packing plants	2011	83/1,275	0.85	71/ 1,084
2. Motor vehicle and car bodies	3711	156/3,750	0.86	134/ 3,225
3. Poultry slaughtering and processes	2015	433/1,244	0.89	385/ 1,107
4. Men's and boy's trousers and slacks	2325	155/571	0.89	138/ 508
5. Men's footwear, except athletic	3143	150/602	0.82	123/ 494
6. Household laundry equipment	3633	500/2,416	0.87	435/ 2,102
7. Household refrigerators and freezers	3632	500/2,550	0.88	440/ 2,244
8. Automotive stampings	3465	93/450	0.83	77/ 374
9. Engine electrical equipment	3694	78/445	0.80	62/ 356
10. Motor vehicle parts and accessories	3714	92/652	0.80	74/ 522
11. Household appliances, n.e.c.	3639	249/1,250	0.84	209/ 1,050
12. Sausages and other prepared meats	2013	73/314	0.80	58/ 251
13. Motorcycles, bicycles, and parts	375	48/562	0.75	36/ 422
14. Knit underwear mills	2254	133/652	0.86	114/ 561
15. Men's and boy's clothing	2326	136/252	0.85	116/ 214

5.1 The Costs Related to MSDs Problems

The costs of MSDs related problems are measured from the workers' compensation costs, the work-related costs, and the labor turnover costs as described in Chapter 3. Medical expenses are calculated according to the number of estimated MSDs cases to get the medical costs. The number of restricted work-activity cases are derived using the estimated number of MSDs cases provided earlier (Table 5.2 provides the number of employee in each SIC where potential MSDs cases are estimated). Workers that are restricted due to MSDs injuries are assumed to perform their duties under normal conditions and the result of a lower performance level when multiply with hourly wage translates into work-related costs. The study is assumed that the work-related loss during restricted work activity due to MSDs injury is estimated to be 1/3 of normal work capacity. The study also assumed that workers with loss days over one month have the potential of leaving the company (See Chapter 3). The replacement cost is estimated to be $3,000, which was derived based on the information suggested by *Andersson (1992), Alexander (1994),* and *Dahle'n and Wennersson (1995).* Assume that the 1/3 of the amount of workers with loss days over a month will be discharged.

Total potential MSDs cost over a six-year period from implementing an ergonomics program for the selected fifteen industries (top quartile) is estimated in Table 5.3. Although using a five-year average and regression approach to estimate future MSD cases over a six-year period may be far into the future extending beyond the significance of a regression function, it should provide a reasonable figure compare to a ten-year estimate used by OSHA's economic study of the former ergonomic standard. Not until the study related to the forecasting of MSDs injuries are determined for each SIC, there is no exact estimate to the projection of future potential MSDs cases. Also, with new information, the averages and regression function can be adjusted. The total cost are in terms of workers' compensation costs, work-related costs, labor turnover costs. The detailed calculations are reported in Appendix C.

Table 5.3 Estimated **total potential cost** ($) that may occur as a result of MSDs injuries for the selected SIC.

SIC	Year1	Year2	Year3	Year4	Year5	Year6
2011	611,640	528,619	444,374	358,904	272,210	184,291
3711	1,493,580	1,505,112	1,516,644	1,528,177	1,539,709	1,551,241
2015	336,624	290,366	243,459	195,903	147,698	98,844
2325	136,764	126,693	116,276	105,515	94,408	82,956
3143	93,345	94,358	95,372	96,385	97,398	98,411
3633	480,308	484,057	487,806	491,554	495,303	499,052
3632	437,851	424,405	410,567	396,336	381,713	366,698
3465	115,105	116,208	117,310	118,413	119,515	120,618
3694	83,124	83,840	84,555	85,271	85,987	86,703
3714	191,902	187,383	182,804	178,167	173,472	168,718
3639	366,979	370,832	374,685	378,538	382,391	386,244
2013	92,215	88,305	84,335	80,305	76,215	72,065
375	244,399	217,321	189,606	161,255	132,268	102,645
2254	407,859	291,092	172,615	52,427	52,427	52,427
2326	92,735	81,990	70,989	59,732	48,219	36,450

5.2 Estimated Ergonomic Investments

The investment needed to complete ergonomics programs for each selected industry is derived from the database. The estimated investment needed for implementing each element of the former ergonomics standard is shown as result. E1 represents the initial program. E2 represents the basic program cost. E3a is the investment needed to implement the job analysis using an ergonomic checklist approach, while E3b is the detailed task analysis. E4ave is the estimated average ergonomic solution cost needed for the selected SIC. E4min is the estimated minimum cost necessary for an ergonomic solution. E5a, E5b, and E5c are the costs of evaluating an ergonomic project for each level of expertise described in Chapter 3. E5ave is the average investment needed for evaluating the ergonomic solution and the entire program. Costs associated to each ergonomics program element for the selected industry described above is estimated in Table 5.4.

Table 5.4 Estimated potential intervention cost ($) that may occur in order to implement an ergonomics program to reduce MSDs injuries for the selected SIC in the top quartile

SIC	E1	E2	E3a	E3b	E4ave	E4min	E5a	E5b	E5c	E5Ave
2011	36,129	18,556	104,042	339,088	397,514	1,808	20,520	171,392	921,267	208,437
3711	145,647	20,390	325,147	611,032	285,809	1,300	24,456	188,942	793,722	197,416
2015	36,266	10,795	80,389	217,029	231,370	1,052	11,995	99,809	536,268	121,371
2325	17,290	1,589	22,820	42,439	88,415	619	1,739	14,388	78,155	17,628
3143	16,523	950	21,905	34,230	52,098	365	1,099	8,547	46,141	10,462
3633	84,690	11,268	151,921	302,019	474,842	4,195	12,342	101,515	471,335	112,401
3632	90,107	9,175	152,205	272,737	151,663	690	10,176	83,503	387,606	92,455
3465	13,727	1,274	29,496	47,746	8,963	1,702	1,710	12,073	58,056	13,789
3694	13,875	1,196	26,005	42,606	9,767	443	1,538	11,149	53,090	12,635
3714	24,930	3,166	52,825	96,930	44,595	203	3,965	29,629	123,993	30,951
3639	42,968	4,791	73,492	137,314	78,424	357	5,338	43,255	200,504	47,884
2013	9,025	1,335	15,326	32,786	27,980	127	1,560	12,179	64,960	14,786
375	18,851	2,795	42,281	80,360	43,626	198	3,663	27,011	117,360	28,890
2254	18,059	7,680	46,284	139,596	466,401	3,264	8,903	73,375	407,783	91,300
2326	7,974	907	10,690	21,801	50,702	355	1,051	8,304	44,872	10,163

The percentage of the investment in each element corresponding to the total investment of the program standard is reported in Table 5.4.1 for both the Ergonomic Checklist Approach and the Detailed Task Analysis. Such reference can be used for the allocation of funds when the total investment expenditures in the selected SIC are known. For example, assume that one company in engine electrical equipment (3694) has the budget to implement an ergonomic project of $50,000. The company would allocate $8,663 for initialization, $747 for basic program, $26,602 for job detailed task analysis, $6,098 for the ergonomic solution, and $7,889 for program evaluation. This approach can help managers to roughly identify the investment needed for each program element.

Table 5.4.1 Percentage of investment for each elements in the former ergonomics standard between ergonomic checklist and detailed task analysis approach.

	Ergonomic Checklist Approach					Detailed Task Analysis				
SIC	E1	E2	E3a	E4ave	E5ave	E1	E2	E3b	E4ave	E5ave
2011	5	2	14	52	27	4	2	34	40	21
3711	15	2	33	29	20	12	2	48	23	16
2015	8	2	17	48	25	6	2	35	38	20
2325	12	1	15	60	12	10	1	25	53	11
3143	16	1	21	51	10	14	1	30	46	9
3633	10	1	18	57	13	9	1	31	48	11
3632	18	2	31	31	19	15	1	44	25	15
3465	20	2	44	13	21	16	1	56	10	16
3694	22	2	41	15	20	17	1	53	12	16
3714	16	2	34	29	20	12	2	48	22	15
3639	17	2	30	32	19	14	2	44	25	15
2013	13	2	22	41	22	11	2	38	33	17
375	14	2	31	32	21	11	2	46	25	17
2254	3	1	7	74	14	2	1	19	65	13
2326	10	1	13	63	13	9	1	24	55	11
Minimum	3	1	7	13	10	2	1	19	10	9
Maximum	22	2	44	74	27	17	2	48	48	21
Mean	13	2	25	42	18	11	1	38	35	15
Median	14	2	22	41	20	11	1	38	33	15

5.3 Project Valuation

When the data related to the costs of MSDs problems and investment needed for ergonomic interventions are identified, ergonomic project valuation is investigated. The study assumes that the benefits of ergonomics program are estimated from the reduction of MSDs related costs. The percent reduction in MSDs related costs is assumed to correlate with the effectiveness of ergonomics program. The net present value of an ergonomic project using the ergonomic checklist and detailed task analysis at various effective rates are estimated in Table 5.5 and Table 5.6. It is observed that if the effective rate of ergonomic intervention were less than 30 percent, it would not be promising to invest in such a high investment cost for some selected industry (2011, 2015, 3633,2254).

Furthermore, it is observed that when detailed task analysis is implemented, a more negative NPV is reported. In addition, the value (NPV) of an ergonomic project can be over-estimated for the ergonomic checklist approach, while underestimated for the detailed task analysis approach. If one were to assign probability for each expected rate of effectiveness (defined in Chapter 3), there would be questions regarding the appropriate probability assignments. Therefore, it would be beneficial to investigate an alternative method for project valuation. Here, the use of real-options for valuing ergonomic investment is recommended.

Table 5.5 Estimated project value using the net present valuation method that may occur in order to implement an ergonomics program with *Ergo checklist* as analysis method to reduce MSDs injuries for the selected SIC in the top quartile Assume interest rate is *20%*.

SIC	Ergonomics program effective rate (%)						
	20	30	40	50	60	70	80
2011	($183,355)	($47,830)	$87,695	$223,220	$358,745	$494,271	$629,796
3711	$220,780	$655,690	$1,090,599	$1,525,509	$1,960,418	$2,395,327	$2,830,237
2015	($144,858)	($70,530)	$3,797	$78,125	$152,453	$226,781	$301,109
2325	($25,448)	$8,892	$43,232	$77,573	$111,913	$146,253	$180,593
3143	($13,079)	$14,242	$41,562	$68,883	$96,204	$123,525	$150,846
3633	($248,823)	($108,945)	$30,934	$170,812	$310,690	$450,568	$590,446
3632	($97,283)	$21,979	$141,240	$260,501	$379,763	$499,024	$618,285
3465	$20,130	$53,749	$87,369	$120,988	$154,608	$188,227	$221,846
3694	$3,804	$28,044	$52,284	$76,523	$100,763	$125,003	$149,243
3714	$971	$53,949	$106,927	$159,906	$212,884	$265,862	$318,841
3639	$48,222	$155,569	$262,917	$370,264	$477,612	$584,959	$692,307
2013	$5,119	$29,730	$54,341	$78,952	$103,563	$128,173	$152,784
375	$24,295	$81,302	$138,310	$195,318	$252,326	$309,333	$366,341
2254	($238,252)	($172,108)	($105,965)	($39,821)	$26,322	$92,465	$158,609
2326	($7,597)	$13,802	$35,201	$56,600	$78,000	$99,399	$120,798

Table 5.6 Estimated project value using the net present valuation method that may occur in order to implement an ergonomics program with *Ergo detailed* as analysis method to reduce MSDs injuries for the selected SIC in the top quartile. Assume interest rate i is *20%.*

SIC	Ergonomics program effective rate (%)						
	20	30	40	50	60	70	80
2011	($346,582)	($211,057)	($75,531)	$59,994	$195,519	$331,044	$466,570
3711	$22,249	$457,159	$892,068	$1,326,977	$1,761,887	$2,196,796	$2,631,706
2015	($239,747)	($165,419)	($91,091)	($16,764)	$57,564	$131,892	$206,220
2325	($39,072)	($4,732)	$29,608	$63,948	$98,289	$132,629	$166,969
3143	($21,638)	$5,683	$33,003	$60,324	$87,645	$114,966	$142,287
3633	($353,058)	($213,179)	($73,301)	$66,577	$206,455	$346,333	$486,212
3632	($180,986)	($61,724)	$57,537	$176,799	$296,060	$415,321	$534,583
3465	$7,456	$41,076	$74,695	$108,315	$141,934	$175,553	$209,173
3694	($7,725)	$16,515	$40,755	$64,995	$89,235	$113,475	$137,715
3714	($29,658)	$23,321	$76,299	$129,277	$182,255	$235,234	$288,212
3639	$3,901	$111,249	$218,596	$325,943	$433,291	$540,638	$647,986
2013	($7,006)	$17,605	$42,216	$66,827	$91,438	$116,048	$140,659
375	($2,149)	$54,859	$111,866	$168,874	$225,882	$282,890	$339,897
2254	($303,052)	($236,908)	($170,765)	($104,621)	($38,478)	$27,665	$93,809
2326	($15,313)	$6,086	$27,485	$48,884	$70,284	$91,683	$113,082

5.4 Project Valuation Using Real Options Approach

The real options method is applied to value ergonomic investments for the selected SIC code. It is suggested from the study that there are at least three types of options that can be applied to ergonomic investments based on OSHA's former ergonomics standard. For example, the option to accelerate or delay job analyses phase, the option to expand ergonomic checklist activities to detailed task analyses, and the option to reduce the costs associated with program evaluation phase. First is the option to accelerate or delay the job analysis element (Element 3). Based on OSHA's former standard, the job analysis element is required to be implemented two years after the standard effective date. During such a period, the job analysis element can be implemented any time before the end of two years. Most ergonomists recommend that early ergonomic intervention can greatly reduce worker's chance of an exposure to MSDs injuries. Therefore, by accelerating the job analysis element should greatly reduce the potential of risk exposure and be able to identify control methods sooner than later. Such benefits from early intervention, the acceleration of job analyses elements, can be measured by an options approach.

The company has the option to accelerate job analysis activities, so that early investigation can be done to identify and understand MSDs problems so that further ergonomic controls can be implemented. Information regarding the quantification of the option to accelerate would be valuable for a decision maker to determine the optimal time to implement job analysis activities. It is also suggested from the study that the option to accelerate can be quantified by measuring the option to implement ergonomic control at two time periods, the base time and the accelerate time period. Then, it would be possible to identify the value of the option to accelerate an ergonomic project based on the difference of the two values. In addition, if the project were to be deferred, the project could be measured analogous to an American call option with dividend and later compared against the base and the acceleration period.

Second is the option to expand from the ergonomic checklist to a full detailed task analysis (Element 3). It is common to categorize job analysis into two groups as mentioned earlier in Chapter 3: ergonomic checklist and ergonomic detailed task analysis. In the real world, a company may implement the ergonomic checklist in order to implement a quick fix solution, which saves more time and resources. Later, a detailed ergonomic task analysis can be established to collect more information related to the MSDs problem and the working environment, so that future ergonomic control can be more effective and directly targeted towards MSDs problems.

However, even though a full detailed task analyses is known to be more effective, they usually cost more than the ergonomic checklist since they require more activities, resources, and time. Should a manager decide to expand ergonomic checklist into a detailed task analyses? Will the increased benefits outweigh the investment cost? Such problem can be viewed in terms of real options. There exists an option to expand job analyses elements from ergonomic checklists to detailed task analyses. From an ergonomics point of view whether to go from a full job analysis, the decision may depend on the knowledge from the checklist activities. The increased benefits are based on a more effective ergonomic control that can reduce or eliminate MSDs problems. Such an option can be measured analogous to an European call option.

Third is the option to reduce the investment costs associated with the program evaluation phase if benefits from such elements are not significant enough to justify the full investment. Assumptions are set that at the time the job analysis element is implemented, one needs only estimate the investment in ergonomic control and the benefits gained from such control. Such estimation processes are usually required for capital budgeting purposes. Nevertheless, the future control and its associated benefits are not known with certainty. Also, when ergonomic controls are implemented, the evaluation of ergonomic control would be needed in order to evaluate the effectiveness of such control as well as the entire ergonomics program. When ergonomic controls are effectively reducing MSDs problems, there may be an option to reduce the investment of the program evaluation phase. Such option has a value that can be measured analogous to the European put option.

The DCF or decision tree approach measures the value of ergonomic control and the evaluation of control as well as its benefits by discounting to the present at the risk-adjusted rate. In the real world, when future knowledge of MSDs problems are known, a more effective ergonomic control will be implemented. The risk involved in the ergonomic control investment reduces because one has gained more information and understanding of the MSDs problems. Therefore, it may not be suitable to use DCF or decision tree method for valuing ergonomic control investments because such a method uses a constant risk-adjusted rate.

The real options approach sees that job analysis acts as an option to buy future ergonomic control where the benefits of such control may vary depending on the findings of the job analysis (at the end of the job analysis maturity date). Such problems can be measured using the real options analogy. Another example of real option is where the investments in ergonomic control create an option to implement control evaluation activities. The assumption for each embedded option is described as follows:

The base case for the analysis will follow some set of assumptions: that E1 and E2 elements are implemented at year 0 since OSHA requires that such elements be implemented within a year from the effective date. The benefits gained from the reduction of MSDs related costs by implementing elements E1 and E2 are estimated to be 5% of the costs of MSDs problems during the first year (See previous section for definitions of E1 and E2).

The job analysis activities (E3) are implemented by the first year (OSHA requires that the job analysis be implemented within 2 years) although the real benefits of job analysis will arise after ergonomic controls are implemented. Nevertheless, job analysis also lead to various control strategies that can increase or decrease the benefits of ergonomic controls. Assume that at the same ergonomic control cost, the detailed task analysis can provide a better assessment of the problem jobs and identify a more effective solution than the ergonomic checklist activities. As a result, a more effective solutions are implemented that reflected in less injuries cases and can be translated to an increase in the benefits of ergonomic control by 30% over the ergonomic checklist. Also assume that the job analysis can generate benefits of 15% during the first and second years by itself because workers are aware and understand MSDs problems.

Furthermore, ergonomic controls (E4) are implemented during the second year and followed by the evaluation of the program (E5) at the end of the third year (OSHA requires that ergonomic control and evaluation must be implemented within 3 years). The benefits (by the reduction of MSDs related costs) from ergonomic control during the second year to the sixth year are assumed to be between 20-80 percent (OSHA recommended 50% as the effective rate for ergonomic intervention while the actual collected data shows that the range of ergonomic effective rates varies from 20-80 percent). The evaluation phase provides feedback for ergonomic control that can increase 25% of the benefits through ergonomic control from the third year to the sixth year (62.5% during year 3-6). Using the assumption above, parameters needed for real options calculation in terms of the reduction of MSDs related costs as a result of an ergonomics program is presented in Table 5.7.

Table 5.7 Present value of the types of benefits generated from ergonomics program elements for the selected SIC.

SIC	Present value of the whole project benefits (1)	Present value of Control (E4) & Evaluation (E5) (2)	Present Value Control Only (E4) (3)	The PV of Evaluation (E5) (4)
2011	424,253	343,703	300,679	74,346
3711	1,829,890	1,610,875	1,376,469	405,054
2015	231,552	187,279	163,912	40,378
2325	125,420	106,524	91,948	25,187
3143	115,428	101,710	86,887	25,614
3633	588,606	518,170	442,766	130,299
3632	473,340	410,887	352,470	100,946
3465	141,801	124,900	106,709	31,435
3694	102,110	89,913	76,824	22,618
3714	212,997	185,482	158,964	45,822
3639	453,321	399,402	341,205	100,565
2013	95,875	82,834	71,148	20,194
375	190,994	158,173	137,511	35,704
2254	137,207	89,890	81,902	13,805
2326	70,690	58,285	50,736	13,044

Table 5.8 Investment costs for each element of the ergonomics program and the net present value of the project in the last column.

SIC	Initiation and Basic Program (1)	Job Analysis Checklist (2)	Detail Task Analysis (3)	Ergonomic Control (4)	Control Evaluation (5)	NPV (6)
2011	54,685	104,042	339,088	397,514	208,437	(4,439)
3711	166,037	325,147	611,032	285,809	197,416	1,412,247
2015	47,061	80,389	217,029	231,370	121,371	(19,290)
2325	18,879	22,820	42,439	88,415	17,628	53,681
3143	17,473	21,905	34,230	52,098	10,462	72,413
3633	95,958	151,921	302,019	474,842	112,401	163,164
3632	99,282	152,205	272,737	151,663	92,455	286,959
3465	15,001	29,496	47,746	8,963	13,789	118,018
3694	15,071	26,005	42,606	9,767	12,635	81,416
3714	28,096	52,825	96,930	44,595	30,951	148,192
3639	47,759	73,492	137,314	78,424	47,884	357,665
2013	10,360	15,326	32,786	27,980	14,786	65,476
375	21,646	42,281	80,360	43,626	28,890	130,392
2254	25,739	46,284	139,596	466,401	91,300	(252,350)
2326	8,881	10,690	21,801	50,702	10,163	29,571

Based on the assumptions given, the net present value that is used for measuring the project values is calculated (Table 5.8 last column). It can be seen right away that the project value for SIC 2011 and 2015 does not look promising. Nevertheless, even though the NPV provides positive value, would a company (SIC 3633) be willing to invest

$985,220 in ergonomics program that will yield a NPV of only $163,164? How can management decision alter the project in the future to improve the upside potential of the ergonomics program and what will be the value of such alteration/modification?

The Real options approach will be used to measure the value of a management decision to alter the ergonomic project. Assumptions are made that management has the ability to accelerate the time to implement the job analysis phase, management can decide to implement the ergonomic checklist and later expand into a fully detailed task analysis if future information shows promising results, and management also has the capability to reduce the investment in the program evaluation phase if the benefits from such a task does not increase MSDs benefits significantly.

5.4.1 Option To Accelerate Job Analysis Activities

Assume that the company has the option to implement the job analysis activities within six months instead of the planned one-year period, so that ergonomic control can be implemented six months sooner. The value of the option to accelerate the job analysis phase is the difference between the value of the option to implement ergonomic control at the second year (base case) against the value of the option to implement ergonomic control six months sooner. Assume that the gross project value or the cash inflow during a six-year period is discounted at the risk-adjusted rate of 20 percent to determine the parameter "V" needed for options valuation.

Let X be the cost of ergonomic control and V be the present value of the ergonomic control if implemented in the second year. Therefore, the ergonomic control for *SIC 2011* is equal to $397,514 (see Table 5.8 column 4), while the present value of the benefits of such control is \$343,703 (see Table 5.7 column 2). Assume that the risk-free rate is 5%, the volatility of such industry is 30%, and the time to maturity is 2 years. The value of the option to implement ergonomic control in the second year will be \$51,773.

If the job analysis can be implemented six months sooner, the ergonomic control would also be implemented six months sooner. The new present value (V_{new}) of the ergonomic control project would be the current present value V plus the additional present value (V_{add}) of the benefits as a result of early intervention ($V_{new} = V + V_{add}$). The additional present value (V_{add}) comes from the half-year of early implementation of ergonomic control and the evaluation of control, which is \$100,533 and \$88,032 respectively. Therefore, the additional present value (V_{add}) from implementing ergonomic control six months sooner is \$188,565, which brings the new present value (V_{new}) to \$532,268. Assume the cost of ergonomic control, risk-free rate, and the industry volatility remain constant. The value of the option to implement ergonomic control at $T = 1.5$, $V_{new} = \$532,268$, $r = 5\%$, $\sigma = 30\%$, and $X = \$397,514$; is equal to \$176,896. The value of the option to accelerate is \$125,123 (the difference between \$176,896 and \$51,773), which is the difference between the value of the option to implement ergonomic control at $T = 2$ and $T = 1.5$.

What if ergonomic control can be deferred six months in order for the job analysis to gain more information about MSDs problems, some loss in cost savings would occur. The value of the option to defer the ergonomic control six months ($T = 2.5$) can be measured using the American option with dividend methodology. The dividend in this case would be the loss cost savings in the second year ($T_{div} = 2$) of \$110,000, if ergonomic control would be implemented six months later. The value of the option to defer ergonomic control will be \$26,845 ($T = 2.5$, $T_{div} = 2$, $V = \$343,703$, $Div = \$110,000$, $X = \$397,514$, $r = 5\%$, and $\sigma = 30\%$). Therefore, the ergonomic control should not be deferred since its option to deferred value is less than the option to implement in the second year (base case) and even much less compared to the value of the option to implement six months early.

5.4.2 Option To Expand Ergonomic Checklist To A Full Detailed Analysis

Assume that an ergonomic checklist is implemented first as a pilot project, where the cost of the checklist *(SIC 2011)* is \$104,042 (see Table 5.8 column 2). By implementing the checklist, there exists an option to expand it into a detailed task analysis within six months. The additional cost of the detailed task analysis is \$235,046 (Table 5.8 column 3 – column 2), which can increase benefits when the ergonomic control is implemented in the second year up to 30%. The present value (V) of the additional benefit is equal to \$103,111. The option to expand the ergonomic checklist to a detailed task analysis can be viewed as a European Call Option. Therefore, the value of the option to expand from an ergonomic checklist to a detailed job analysis will be \$276 ($V = \$103,111$, $T = 1.5$, $X = \$235,046$, $r = 5\%$, and $\sigma = 30\%$). Even though for SIC 2011 the value of the option to expand to an ergonomic checklist may not worth much, the value of such an option may be higher for different sets of assumptions. It can be that for some industry, the investments in an ergonomic checklist would be enough to reduce the MSDs problems in the workplace.

5.4.3 Option To Reduce The Cost of Program Evaluation

Assume that the cost of a program evaluation may be reduced in half when future ergonomic controls prove to be effective and there is no longer much need for the modification of controls *(SIC 2011)*. Therefore, the benefits from the program evaluation phase may not be significant enough to justify the full investment costs. The company may decide to reduce the planned investment in the program evaluation phase. The option to reduce the cost of the program evaluation phase can be measured analogous to the European put option where the cost savings of the program evaluation phase is the exercised price.

When future ergonomic control does not reduce MSDs problems significantly, a full program evaluation will be needed. The estimated present value (V) of the benefits gained from a program evaluation is $74,346 (see table 5.7 column 4). Assume the cost that can be avoided is $104,218 (X) (half of the control evaluation costs of $208,437), the time to implement the program evaluation is in the third year (T = 3), and the risk-free rate and industry volatility remain the same (r = 5%, and σ = 30%). The value of the option to reduce investment in the program evaluation is calculated as $25,422. Based on the analysis described above, it is suggested that the three options embedded in the ergonomics standard program are not fully captured using the standard DCF method. The option value of each embedded option in ergonomics program for the selected SIC is presented in Table 5.9.

Table 5.9 The embedded option's value ($) in OSHA's former ergonomics standard.

SIC	Option to accelerate (A)	Deferred option (D)	Option to invest as planned (G)	Expand option (E)	Option to contract (R)	NPV
2011	125,123	26,845	51,773	276	25,423	-4,439
3711	339,871	1,325,066	1,351,910	220,601	23	1,412,247
2015	33,243	10,665	22,902	86	16,617	-19,290
2325	22,210	25,740	32,248	13,971	23	53,681
3143	20,181	52,018	54,897	19,072	0	72,413
3633	74,073	101,616	131,634	30,315	412	163,164
3632	93,468	263,804	273,554	23,167	479	286,959
3465	26,546	115,937	116,779	20,566	0	118,018
3694	19,074	80,146	81,063	11,757	3	81,416
3714	41,870	141,117	145,076	16,572	34	148,192
3639	83,597	320,978	328,344	60,793	4	357,665
2013	19,493	55,544	57,492	9,087	24	65,476
375	47,855	114,578	118,646	13,780	63	130,392
2254	18	0	0	1	25,619	-252,350
2326	14,110	12,336	16,334	7,320	20	29,571

5.4.4 Multiple Options Interaction

When more than a single option exists, the valuation of such multiple options can be measured as compound options. The value of the embedded option in a later stage acts as an additional benefit to the cash inflow for the predecessor options, for example, when management has the ability to accelerate the job analysis phase and later upgrade job analysis from the ergonomic checklist to a detailed analysis. The value of the option to upgrade job analysis is added to the value of the cash inflow or present value in order to calculate the value of the option to accelerate.

Another example of compound option is when the value of the option to reduce the investment in program valuation is added to the underlying present value of the option to expand. Such options interaction can be measured using the same concept as pricing compound options. It is illustrated in Table 5.10 that the value of such options interaction which management can make in the future, can be added to the projects net present value in order to achieve the total project's value or the expanded net present value (ENPV).

Table 5.10 The value ($) of real options interactions in ergonomics program.

SIC	A&E	A&R	E&R	A&E&R	Selection
2011	66,932	85,715	1,786	121,076	A&R
3711	655,022	339,875	220,623	2,006,936	A&E
2015	33,516	46,001	764	57,653	A&R
2325	43,396	22,221	13,993	75,654	A&E
3143	45,454	20,181	19,072	100,351	A&E
3633	119,467	74,275	30,624	251,279	A&E
3632	134,789	93,757	23,527	408,598	A&E
3465	54,670	26,546	20,566	171,449	A&E
3694	36,044	19,076	11,760	117,109	A&E
3714	68,742	41,881	16,603	213,829	A&E
3639	168,287	83,598	60,797	496,632	A&E
2013	33,806	19,507	9,109	91,312	A&E
375	73,900	47,901	13,836	192,590	A&E
2254	18	173	932	21	E&R
2326	26,097	14,122	7,339	42,444	A&E

It can be observed that the value of the options interaction is not equal to the sum of single options. The values of embedded options are non-additive. Nevertheless, the value of individual options increase the total project's value significantly. For example, by implementing an ergonomics program for SIC 3633, the project value has now increased from an NPV of $163,164 to ENPV of $414,443. The value of the project is almost half of the required investment expenditure needed for the entire program of $985,220. In other words, by implementing an ergonomics program, the company will profit by $414,443, while the required investment is $985,220. The study also found that the value of management flexibility to accelerate, expand, and contract has increased the project value, up 254 percent or 2.54 times its original value (for SIC 3633).

It is indicated in Table 5.11 that the increase in the project's value from its original planned NPV when the three real options are under consideration. By considering the three embedded options, the average project value would increase 2.43 times of the project's original value as clearly seen from the study results. Finally, from evaluating the options interaction among different SIC's, the study found an average increase in the project's value when each type of option and its interactions are accounted in the management decision-making process (Table 5.12).

Table 5.11 The increase in a project's value when management flexibility is under consideration (A&E&R = 2.43).

SIC	NPV	A&E&R	ENPV	Increase in project value
2011	-4,439	121,076	116,637	-26.28
3711	1,412,247	2,006,936	3,419,183	2.42
2015	-19,290	57,653	38,363	-1.99
2325	53,681	75,654	129,335	2.41
3143	72,413	100,351	172,764	2.39
3633	163,164	251,279	414,443	2.54
3632	286,959	408,598	695,557	2.42
3465	118,018	171,449	289,467	2.45
3694	81,416	117,109	198,525	2.44
3714	148,192	213,829	362,021	2.44
3639	357,665	496,632	854,297	2.39
2013	65,476	91,312	156,788	2.39
375	130,392	192,590	322,982	2.48
2254	-252,350	21	-252,329	1.00
2326	29,571	42,444	72,015	2.44

Table 5.12 The increase in a project's value when management flexibility is under consideration for each type of options interaction.

Type of Option	The average increase in project's value
A	1.32
E	1.17
R	0
A&E&R	2.43
A&E	1.58
A&R	1.32
E&R	0

From analyzing the percent increase in the total project when embedded options are added, the study suggests that based on the information provided in the study, the acceleration option accounted for the majority portion of the options interaction (A&E&R). Such finding confirms with other authors that an ergonomics program will reduce MSDs hazards significantly when early interventions are implemented. Furthermore, the value of deferring ergonomic intervention does not improve the project value as compared with implementing as planned or accelerating the project.

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1 Discussion

Even though ergonomic project selection should be determined based on the prevalence of injuries and illnesses, a cost justification of the project is necessary for management decision making. Studies have found that ergonomic cost justification can be difficult because of the lack of data collection, the nature of investment, or the limited understanding of the cause/effect relationship of ergonomic intervention and work-related MSDs. Still, decision-makers rely on the analysis provided by the cost justification and project valuation to evaluate ergonomic projects. The database for the cost/benefit estimation is developed using a large-scale national database as opposed to collecting data from specific cases. The advantage of using large-scale database is to avoid potential bias that may occur in success and un-success case studies. Although there are several assumptions needed in estimating ergonomic investments for an ergonomics program, the derivation of the investment was structured using the most available data. The study tries to minimize the arbitrary guessing of cost/benefit value by using averages and regression function when the data are not available. The study laid out the information needed for estimating the costs and benefits of ergonomic interventions.

It is introduced from the dissertation that a database that can estimate parameters needed for cost/benefits estimation. Several MSDs related costs are used in this study, those are workers' compensation costs, work-related costs, and labor turnover cost as the cost-savings parameters for measuring the potential benefits of ergonomics programs.

The three potential cost savings were derived, based on the *nature of illnesses* and *exposure types* that are related to MSDs. The uses of the number of lost days cases with days away from work, and the number of restricted work-activity cases to predict the workers' compensation cost savings, work-related cost savings, and labor turnover cost savings are also brought up in this study. As results it makes possible to distinguish the percentage of overexertion cost, repetitive motion cost, and bodily reaction cost that are a part of the workers' compensation cost, or work-related cost, or labor turnover cost. Such knowledge of detailed cost/benefit elements can tremendously help decision-makers in setting priorities and directing limited resources more efficiently. Furthermore, companies can use the estimated expenditures as a guideline and benchmark for the investment planning while following OSHA's former ergonomics standard.

The framework not consisted only the method to estimate the cost/benefit of an ergonomics program, but included a way to value ergonomic projects as strategic investment. Therefore, it is very important to be able to quantify strategic consideration embedded in ergonomics program investments. Traditional economic valuation approaches use the outcome of the DCF method as selection criteria in order to properly implement ergonomic interventions. However, researchers in the field of finance have identified that the DCF method has its disadvantages in valuing staged projects when there are uncertainties in future outcomes. Projects with uncertainty in cash flow, timing of implementation, or management flexibility such as ergonomic projects, can be undervalued using DCF methods. The NPV of the project can be negative, which results in an unattractive project. The value of management flexibility, which is the ability to make changes when future circumstances change, cannot be realized using traditional methods. Management can be misled in selecting projects that do not fully prevent ergonomics problems, using the DCF method. One approach to fully value ergonomic projects is to reduce the uncertainty in the estimated cash in-flow/out-flow, which is the benefit of ergonomics and its investment cost.

Even though the framework tries to minimize the uncertainty of the estimated cash flow by using regression models and averages, uncertainty still exists due to various reasons such as the technology advances which can identify specific dose/response more accurately, the market demand for a product may cause workers to produce more/high output and result in MSDs injuries, the differences in workers' physical condition that can result in the timing of onset of MSDs, the fluctuation of medical costs, or workers' performance while on restricted work activities varies among workers. The regression models and averages used for estimating the cost/benefit in this framework does not include effects of these uncertainties. Therefore, in order to account for such uncertainties, a valuation method that has the potential of capturing uncertainty and strategic consideration was investigated.

The real options approach was investigated and demonstrated to be a promising method for valuating strategic ergonomic investment. Three types of real options that existed in ergonomics program are identified in this study, those are, the option to accelerate task analysis activity, the option to expand from ergonomic checklist to a detailed task analysis, and the option to reduce the investment in control/program evaluation. It is found that the option to accelerate task analysis activity was the highest value creation for the ergonomics program (1.32) followed by the option to expand from ergonomic checklist to a detailed task analysis (1.17). Even though the real options applied may be based on the structure introduced, the option to reduce the investment in *control/program evaluation* does not provide much additional value or in some cases provides none. Nevertheless, companies should still consider such an option valuable. The reason is that, when ergonomic solutions have improved the working environment effectively, the full program evaluation may not add much to the MSDs improvement as illustrated for the meat packing industry (SIC 2011). On the other hand, the analysis confirms that project evaluations are necessary for an ergonomics standard program, and only in certain situations that the reduction in such investment be beneficial.

There are two main contributions to the field: First, the framework provides a cost-benefit estimation mechanism that is needed for ergonomics program valuation. In addition, the study helps to standardized data collection that are needed in order to construct information related to ergonomic intervention and cost reduction so that ergonomic justification can be established. It is suggested from the study that BLS should report information related to MSDs in a more detailed breakdown so that MSDs cases with days away from work and with restricted work-activities are breakdown into the *nature of injury and illness* within each type of exposure for any given SIC. The BLS information should be define clearly during data collection so that with the advances in information technology these information can be made available in order to reduce the estimated figures. Furthermore, it is demonstrated in the study that the integration of public accessible data sources such as OSHA's former ergonomics standard and BLS data so that cost-benefit function can be developed to estimate potential benefits and investment expenditures. Such approach avoids the bias that existed in a single case study. The information system can be useful when the decision-makers do not have resources and information available to estimate the cost-benefit that can occur from implementing ergonomics program. The cost-benefit estimate can act as a benchmark and guidelines for company's planned ergonomics program.

The second contribution in this dissertation is the introduction of an alternative cost justification tool, using real options to evaluate ergonomic intervention projects. The study describes the types of real options that existed in ergonomics program. Using real-options to value ergonomic projects can measure the value of management flexibility, to adapt its future actions in response, and to alter investment to improve future health and safety conditions. By including the management flexibility into ergonomic projects valuation, reduces the possibility of undervaluing an ergonomic project. Such valuation approach can be used to determine the market value of an ergonomic project that can be comparable against investment in financial markets. The research presents ergonomic project selection in a different view, a more active than passive approach. It is hoped that more ergonomic projects can be implemented when management sees their true value.

The study can increase the attention of real-options methodology that can be applied in other fields of industrial engineering that requires projection of uncertain cash flow, such as investments in just-in-time manufacturing, design for manufacturability, or flexible scheduling systems. Even though a tremendous amount of research in the field of real-options has emerged since the late 1980s, yet the dominant project valuation method remains the net present value. While most of the real-option studies focus on the mathematical model development, the practical side of applying real options in real world application is limited. Adapting the use of real options for valuing strategic ergonomic intervention can increase the validity of the method and act as an alternative economic valuation method for industrial engineers.

Furthermore, the breakthrough of the research to the ergonomics community is that of value creation. Even though in the past ergonomic projects were viewed as cost centers or expenses to the company, the study provides a quantitative way to view ergonomic interventions as an investment that create additional value to the bottom line. By seeing ergonomic intervention as a value creation investment, ergonomic projects can be seen as one of the factors to generate growth to the company where the bottom line is to increase the value to the company's shareholders.

6.2 Limitation

The main limitations of the study can be grouped into two categories, the estimation of cost/benefit of ergonomics program, and the ergonomic project valuation using real options. First is the limitation and accuracy of the estimated benefits of an ergonomics program, and the associated investments expenditures. Even though it is possible to build the database from scratch using public information, the completeness of the information system can greatly enhance the accuracy of the MSDs incidence forecast for each SIC. Moreover, the estimated investments cost can vary tremendously among different companies and working environments. The applicability of the cost/benefit estimation should not be used blindly, but rather enhance the understanding of an ergonomics program valuation so that decision-maker will have enough knowledge to move forward in ergonomic planning under limited resources. Furthermore, the study did not take geographic location into consideration for cost/benefit estimation. The costs/benefit in different regions of the country may be significantly different. Further study is needed to adjust cost/benefit figures according to the geographic location.

The limitation of using real options to value ergonomic projects exists. One is that in some cases, it may not be obvious to identify real-option characteristics embedded in ergonomic interventions. For example, in the case study (Chapter 4 section 4.3), the benefits associated with stage 1 and stage 2 were allocated based on some percentage assumptions. When cost savings are difficult to allocate due to a specific intervention, the estimate of percentage must be made. In other words, it can be difficult to distinguish the percentage of ergonomic benefits belonging to stage 1 or stage 2. Another problem is the maturity date related to the time period that an ergonomic solution could be implement (such a time frame is difficult to estimate). Expert opinions to compare the intervention project with that of a similar industry may be needed to be able to estimate the benefits and their associated variance, the time period, and investment costs. When benefits generated from a particular intervention are known with certainty (which is rarely found), real-options valuation offers no advantages over the DCF method. Also, the actual data of ergonomic projects and their effectiveness, the benefit part, is limited in the current study.

6.3 Future Research

The extension of the study can be in three groups. One is related to the completeness and accuracy of the cost/benefit model, second is related to applying the framework in the real world, third is to formulate standardized real options model for ergonomic investment. More data may be needed in order to correct the regression function used in estimating the benefit models so that it can capture the cyclical and geographical effects as well as the gradually reduction of MSDs cases instead of a steep slope for some SIC. As time passes, changes in the incidence rate vary among industries, an updated regression functions are needed. Therefore, further work can be done to improve the database so that it can be smart enough to update new data source instead of having a DBA to select the data and update the database. More research can be done to investigate the relationships and correlation of the benefit parameters introduced against other cost elements such as quality costs. The effectiveness of ergonomic intervention can be investigated, either with a simulation approach or utilizing actual data. When such knowledge increases, the validity of the cost justification could improve tremendously. In addition, more work can be done to integrate the effects of geographic region and occupation type into the cost/benefit estimate. Furthermore, studies are needed to find the mechanism of maintaining and updating the database and use the constructed data collection to actively capture future health and safety intervention and its benefits. Also, there may be other cost analysis tools that can be applied in analyzing MSD costs such as the Quality Cost Analysis Control approach since ergonomics program have similar cost characteristics as the Quality Assurance Program namely; Prevention costs, Appraisal Cost, and Failure Costs *(Companella, 1983)*.

Even though it is difficult to motivate companies to participate in such studies, future research related to applying the justification framework in the real world environment would greatly confirm the validity and consistency of the method. Like any other valuation framework, the more the company applies, the more significant is the methodology. The intent of such methodology is to invest in ergonomics effectively, which will result in a better working environment and the reduction of MSDs in the workplace. The validation the cost/benefit justification framework by apply the method for a specific company can be difficult without the development of a decision support system based on this concept. A user-friendly interface is needed so that companies can utilize the framework efficiently. Also, further study can be done to integrate the cost-benefit and project valuation with a framework that has the capability to guide the users step by step to look for ergonomic solutions and make a choice among different options.

Other future research areas are those related to the modeling of ergonomic investments as real-options. Future studies may find other options embedded in ergonomic investment. The two possible real-options embedded are the option to abandon the ergonomic project and the option to switch among different types of ergonomic controls, or the option to switch workers skills through cross training. Additional investigation will be needed in order to define, structure, and collect data necessary for such valuation. Such research can enhance the concept of strategic ergonomic investment significantly, since more quantitative valuation of ergonomic interventions are available. The dissertation is not just for Ergonomic projects. Future studies may use the same approach in other areas, such as other health and safety issues.

6.4 Summary and Conclusion

A cost/benefit justification framework for ergonomics programs to reduce work-related MSDs is introduced in this dissertation. The framework consists of three major components: the database that estimates the potential benefits that can be gained through ergonomic intervention, the database that estimates the investment needed for an ergonomics program, and the project valuation. A database for estimating the benefits of ergonomics programs to reduce WMSDs for a specific industry according to its standard industrial code (SIC) is developed so that injury cases can be checked by exposure types (e.g., overexertion, bodily reaction, repetitive motion, etc.) and injury/illness types (e.g., sprain/strain, back pain, CTS, tendonitis, etc.) according to the categorization by Bureau of Labor Statistics (BLS). The database uses data collected from BLS (1993-1997), Healthcare Cost and Utilization Project (1993-1996), and research findings to formulate an information system that can determine the potential benefits of reducing WMSDs. The estimated benefits of ergonomic projects are derived from the reduction of workers' compensation costs, work-related costs, and labor turnover costs. The dollar figures used in the database are adjusted to the same year through out the entire study.

An attempt was made to estimate the total potential cost savings gained over a six-year period from implementing ergonomics programs for the selected fifteen industries as a group using the developed database. Out of the total potential cost savings, 83% is attributed to workers' compensation savings, 11% due to savings of work-related cost, and 6% is from savings of reduction labor turn over. If one looks at cost savings in term of exposure type, the overall cost savings among the fifteen selected industry come from ergonomics effort/activities addressing the problem of overexertion (58%), bodily reaction (15%), and repetitive motion (27%). It makes possible from this study to identify the proportion of exposure types that contribute to the overall costs savings, so that managers can prioritize ergonomic analysis and control activities appropriately.

The second component is the database that estimates the investment necessary for the implementation of the former ergonomics standard by OSHA. The cost to implement ergonomic projects for each SIC follows the structure of OSHA's former ergonomics standard that outlines five elements, namely initialization, basic program, task analysis, ergonomic control, and program evaluation (OSHA, CFR1910.900). The estimation of the ergonomic solution was based on the type of industry. The estimated ergonomics program investment costs should not be compared across industries blindly, but rather used as a benchmark for ergonomic budget planning. The proportions of investment consumed by each ergonomics program elements are calculated.

The third component of the framework is the project valuation that uses the NPV and the real-options methodology to quantify strategic ergonomic investment. The framework described was applied in ergonomics program valuation for fifteen selected industries (SIC). A base case was set up to measure the cost/benefits justification of the selected SIC using the introduced framework for a period of six years. The benefits and investment cost was reported and evaluated using the net present value method as well as the real-options approach. The costs and benefits of implementing ergonomics programs are calculated based on the NPV method at various effective rates for each SIC. The study observed that if the effective rate of ergonomic intervention were less than 30 percent, it would not be promising to invest in such a project for some selected industry (e.g., 2011, 2015, 3633, 2254).

It is investigated from this study that the applicability of real-options valuation to be used in ergonomic project valuation and found it promising. Three types of embedded options that exist in ergonomic investment projects are introduced from this study, they are: the option to accelerate the job analysis activity, the option to expand the ergonomic checklist to a detailed task analysis, and the option to contract the full program evaluation phase. It is found that the value of the project increases when embedded options are added. The additional value of a single option (accelerate, expand, and contract) as well as the interaction of multiple embedded options are also investigated. It is shown that the three embedded options, when interacting, can increase the project value up to 2.43 times its original value, while a single acceleration option and a single expansion option added 1.32 times and 1.17 times its original value, respectively.

Furthermore, it is found that the ability to measure the opportunity to implement an ergonomic project in the future, as opposed to seeing an ergonomic project as a whole single project, prevents managers from undervaluing ergonomic projects. Such value is comparable to investing in a similar risk return trade-off as an investor would invest in a financial market. The intent is to provide additional perspective to an alternative tool for valuation and selection of an ergonomic project as opposed to the discounted cash flow method. For companies to comply with OSHA's former ergonomics standard, ergonomic intervention is needed. It is hoped that this justification method and findings can help companies to justify the value of an ergonomic intervention and act as alternative criteria in the selection of ergonomic projects. It is hoped that ergonomic projects can be viewed as an investment that can bring in cost savings to the company when the cost/benefits information is available for management decision making.

APPENDIX A

DATA COLLECTION

The data that is used for estimating the benefits of ergonomics intervention as well as the cost to comply are based on national databases. This section describes the origin of such data that are being used in the modified framework.

A.1 Bureau of Labor Statistics Database (BLS)

The information extracted from the BLS was mainly to identify the statistical information related to the incidence rate, days away from work due to the type of exposure, the nature of illness for a selected industry, and occupation code. Such data are extracted for the time period between 1993-1997. The URL locator of such information is http://stats.bls.gov/oshc_d93.htm to http://stats.bls.gov/oshc_d97.htm. The structure of the BLS information can be grouped as shown in Table A.1.

Table A.1 Data from BLS web site

Selected parameters	Case/Incidence rate	Detailed			
		Nature of illness	Body part affected	Source of injury	Event or exposure
Industry code	Cases	R1	R2	R3	R4
	Incidence rate	R5	R6	R7	R8
Occupation code	Cases	R9	R10	R11	R12
Selected Nature of illness	Cases	N/A	R13	R14	R15
	Incidence rate	N/A	R16	R17	R18
Body part	Cases	R19	N/A	R20	R21
	Incidence rate	R22	N/A	R23	R24
Source	Cases	R25	R26	N/A	R27
	Incidence rate	R28	R29	N/A	R30
Event or exposure	Cases	R31	R32	R33	N/A
	Incidence rate	R34	R35	R36	N/A
Days away from work	Cases	R67	R68	R69	R70

Another part of the information was extracted from the BLS database that is located at http://www.stats.bls.gov/oshsum97.htm. This source provides the statistics related to the number of workers with lost workdays due to injury and illness for each SIC. The information is used in estimating MSD cases that result in work-restricted activity cases.

A.2 Healthcare Cost and Utilization Project (HCUP-3)

HCUP-3 is a federal-state-industry partnership to assemble healthcare data to be used in health services research and policy analysis. Such information is based on the Nationwide Inpatient Sample (NIS), which contains all discharge records from a 20% sample of U.S. community hospitals in 17 states. The URL of such information is located at http://www.ahcpr.gov/data/hcup/hcupstat.htm. The research framework uses HCUP-3 as an approximation of the medical expenses due to work-related MSD illness. The data were extracted from HCUP-3 for the period of 1993 to 1996.

HCUP-3 reports statistical information related to the mean length of stay (LOS), the mean total charge, the number of total discharges, and the percentage of total discharges categorized by three types of classification schemes. The mean total charges represent the dollar amount charged for the hospitalization rather than the amount paid or the actual costs to provide the care. Physician payments are not included. Still, such information represents one way to approximate the costs of hospital care. The classification schemes that are used in HCUP-3 categorization are the Diagnosis Related Group (DRG), and the Clinical Classification for Health Policy Research (CCHPR).

A.2.1 Diagnosis-Related Groups (DRG)

DRG are a classification of hospital case types into groups expected to have similar hospital resource use. Medicare uses this information to pay for inpatient hospital care. The groupings are based on diagnoses, procedures, age, sex, and the presence of complications. The selected DRG that represent illnesses and injuries of work-related MSD are extracted from the HCUP-3 to be used for the approximation of medical expenses. Table A.2 shows such selected DRG.

A.2.2 Clinical Classification for Health Policy Research (CCHPR)

CCHPR was developed as a way to classify diagnoses and procedures into clinically meaningful categories for use in aggregate statistical reporting. Unlike DRGs, CCHPR classifies single diagnoses (DCCHPR) and single procedures (PCCHPR) into clinically similar groups. The DCCHPR was used to classify principal diagnoses into 260 diagnosis categories, while the PCCHPR was used to classify principal procedures into 231 procedure categories. The selected DCCHPR and PCCHPR that represent illnesses and injuries of work-related MSD are extracted from the HCUP-3 to be used for the approximation of medical expenses. Table A.3 shows such selected DCCHPR.

Table A.2 Selected DRG that are assumed to represent illnesses/injuries of work-related MSD

DRG	DESCRIPTION - VERSION 12 AP-DRG	Total Cases	Prob Discharge	Average Charges	Average LOS
004	SPINAL PROCEDURES	25,728	0.07	$ 22,547.00	9.01
006	CARPAL TUNNEL RELEASE	2,019	0.01	$ 5,790.00	2.47
009	SPINAL DISORDERS & INJURIES	8,225	0.02	$ 14,318.00	11.90
010	NERVOUS SYSTEM NEOPLASMS W CC	47,824	0.14	$ 11,844.00	8.84
011	NERVOUS SYSTEM NEOPLASMS W/O CC	10,670	0.03	$ 7,580.00	4.78
012	DEGENERATIVE NERVOUS SYSTEM DISORDERS	45,969	0.13	$ 12,717.00	13.90
015	TRANSIENT ISCHEMIC ATTACK & PRECEREBRAL OCCLUSIONS	198,870	0.57	$ 6,237.00	4.73
022	HYPERTENSIVE ENCEPHALOPATHY	6,063	0.02	$ 7,729.00	5.29
034	OTHER DISORDERS OF NERVOUS SYSTEM W CC	34,015	0.10	$ 11,608.00	9.23
035	OTHER DISORDERS OF NERVOUS SYSTEM W/O CC	17,290	0.05	$ 6,233.00	5.16
223	MAJOR SHOULDER/ELBOW PROC, OR OTH UPPER EXTREMITY PROC W CC	64,683	0.19	$ 7,087.00	2.62
224	SHOULDER,ELBOW OR FOREARM PROC, EXC MAJOR JOINT PROC, W/O CC	53,615	0.15	$ 6,419.00	2.09
226	SOFT TISSUE PROCEDURES W CC	16,460	0.05	$ 12,502.00	6.39
227	SOFT TISSUE PROCEDURES W/O CC	42,477	0.12	$ 6,503.00	2.46
228	MAJOR THUMB OR JOINT PROC,OR OTH HAND OR WRIST PROC W CC	12,357	0.04	$ 8,618.00	3.19
229	HAND OR WRIST PROC, EXCEPT MAJOR JOINT PROC, W/O CC	21,739	0.06	$ 6,242.00	2.08
233	OTHER MUSCULOSKELET SYS & CONN TISS O.R. PROC W CC	14,008	0.04	$ 20,650.00	9.61
234	OTHER MUSCULOSKELET SYS & CONN TISS O.R. PROC W/O CC	17,690	0.05	$ 10,117.00	3.52
238	OSTEOMYELITIS	16,617	0.05	$ 13,477.00	11.41
240	CONNECTIVE TISSUE DISORDERS W CC	26,966	0.08	$ 12,278.00	8.12
241	CONNECTIVE TISSUE DISORDERS W/O CC	16,853	0.05	$ 5,838.00	4.50
243	MEDICAL BACK PROBLEMS	245,111	0.71	$ 5,583.00	5.24
246	NON-SPECIFIC ARTHROPATHIES	3,952	0.01	$ 5,452.00	4.90
247	SIGNS & SYMPTOMS OF MUSCULOSKELETAL SYSTEM & CONN TISSUE	29,583	0.09	$ 5,601.00	4.84
248	TENDONITIS, MYOSITIS & BURSITIS	22,321	0.06	$ 6,241.00	5.29
249	AFTERCARE, MUSCULOSKELETAL SYSTEM & CONNECTIVE TISSUE	21,536	0.06	$ 7,134.00	7.01
250	FX, SPRN,STRN & DISL OF FOREARM, HAND, FOOT AGE >17 W CC	7,497	0.02	$ 6,431.00	4.66
251	FX, SPRN,STRN & DISL OF FOREARM, HAND, FOOT AGE >17 W/O CC	12,178	0.04	$ 4,072.00	2.51
256	OTHER MUSCULOSKELETAL SYSTEM & CONNECTIVE TISSUE DIAG	33,785	0.10	$ 6,962.00	5.22
	TOTALS	34,714,497	100.00	$ 9,833.00	5.79

Table A.3 Selected DCCHPR that are assumed to represent illnesses/injuries of work-related MSD

Expanded Clinical Classifications for Health Policy Research (CCHPR) category (1)	Number of discharge	Percent of discharge	Mean charges	Mean LOS
All Discharges	34,872,474	100	$10,647	5
6.9 Other nervous system disorders [95.]	106,730	0.31	$12,427	5.9
6.9.1 Disorders of the peripheral nervous	46,236.0	0.13	$ 14,538	5.9
6.9.2 Other central nervous system disorders	33,441	0.1	$13,360	6
6.9.3 Other nervous system symptoms and symptoms and disorders	27,052	0.08	$7,711	5.5
13 Diseases of the musculoskeletal system and cognitive tissue	1,391,458	3.99	$14,032	4.7
13.1 Infective arthritis and osteomyelitis (except that caused by TB or STD) [201.]	68,133	0.2	$17,744	9.6
13.2 Non-traumatic joint disorders	482,011	1.38	$18,252	5.1
13.2.1 Rheumatoid arthritis and related disease [202.]	26,068	0.07	$14,600	5.5
13.2.2 Osteoarthritis [203.]	415,264	1.19	$19,423	5.2
13.2.2.1 Osteoarthritis, localized	239,763	0.69	$19,901	5
13.2.2.2 Osteoarthritis, generalized and unspecified	175,501	0.5	$ 18,776	5.3
13.2.3 Other non-traumatic joint disorders [204]	40,680	0.12	$ 8,686	3.9
13.3 Spondylosis, intervertebral disc disorders, other back problems [205.]	519,130	1.49	$10,576	3.4
13.3.1 Spondylosis and allied disorders	60,123	0.17	$13,576	4.4
13.3.2 Intervertebral disc disorders	329,181	0.94	$10,110	2.9
13.3.3 Other back problems	129,826	0.37	$10,378	4.2
13.3.3.1 Cervical radiculitis	5,453	0.02	$8,298	2.9
13.3.3.2 Spinal stenosis, lumbar region	65,792	0.19	$13,056	4.6
13.3.3.3 Lumbago	20,057	0.06	$5,548	3.9
13.3.3.4 Sciatica	3,988	0.01	$5,570	4.1
13.3.3.5 Thoracic or lumbosacral neuritis or radiculitis, unspecified	9,401	0.03	$7,940	4
13.3.3.6 Backache, unspecified	7,022	0.02	$5,630	3.7
13.3.3.7 Other back pain and disorders	18,114	0.05	$10,882	4.1
13.8 Other connective tissue disease [211.]	104,078	0.3	$9,663	4.1
16 Injury and poisoning	2,718,444	7.8	$14,646	5.4
16.1 Joint disorders and Dislocations, trauma-related [225.]	61,531	0.18	$9,843	2.6
16.3 Spinal cord injury [227.]	12,835	0.04	$56,786	16.3
16.7 Sprains and strains [232.]	86,184	0.25	$6,386	2.3

Note: The average charge and length of stay information for 1997 was extracted from the inpatient information from the State of New Jersey, classified by DRG. The URL locator is at http://www.state.nj.us/health/hcsa/95payl.htm

A.3 OSHA Proposed Ergonomics Program

The information related to ergonomics standard compliance costs was extracted from http://www.osha-slc.gov/ergonomics-standard/tables/Chapter5.html. The compliance costs component can be categorized into familiarization costs, the costs to implement the basic program, the costs to implement the full program, the costs of ergonomics control intervention, and the costs to provide work-restriction protection (WRP). The cost structure and assumptions that OSHA used in determining the compliance costs can be summarized in Table A.4.

Table A.4 Assumption used to develop costs for provision of the proposed rule.

Provision	When required	Hours or costs involved	Level of staff or expertise required
Familiarization Costs to Review Standard to Determine applicability to Establishment and Ability to Grandfather In (Cost to All General Industry Firms)	Initially for all establishments in general industry	1 Hour	Manager
Cost to Investigate whether an MSD or Persistent Symptoms are Covered by the Standard (Cost to All General Industry Firms)	All establishments with manufacturing or manual handling jobs; for other general industry establishments, only when an MSD occurs	0.25 hour of managerial time and 0.25 hour of employee time per recordable MSD	Manager who has received initial training
Cost to Implement Initial Program (designating responsible persons, providing resources, etc.) (Basic Program)	Establishments with basic programs: all with manual handling or manufacturing jobs; otherwise, only if MSD occurs	1 Hour	Manager with initial training
Cost to Provide Managerial Training as Part of Management Leadership (Basic Program)	Establishments with basic programs: all with manual handling or manufacturing jobs; otherwise, only if MSD occurs	2 Hour	Manager
Cost to Set up Reporting System (Basic Program)	Establishments with basic programs: all with manual handling or manufacturing jobs; otherwise, only if MSD occurs	1 Hour	Manager with initial training
Cost to Provide Employee Information (Basic Program)	Establishments with basic programs: all with manual handling or manufacturing jobs; otherwise, only if MSD occurs	0.5 hour per employee plus 0.5 hour managerial time	Manager with initial training
Cost to Provide Managerial Training in Establishments with Full Program	If persistent symptoms or an MSD occurs in manufacturing or manual handling establishments; otherwise, only when an MSD occurs	16 hours of managerial time	Manager with initial training
Cost to Train Employees in Establishments with Full Programs	All establishments having problem jobs	1 hour of employee time per affected employee, 2 hours of managerial time per problem job to provide training; 25% of employers able to use quick fix option and these therefore do not need to conduct employee training.	Manager with training required for the full program

Table A.4 (Continued)

Provision	When required	Hours or costs involved	Level of staff or expertise required
Cost of Job Hazard Analysis (Full Program)	All establishments with problem jobs	1 hour of managerial time plus 1 hour employee time per problem job	Manager with full program training
Provision	When required	Hours or costs involved	Level of staff or expertise required
Cost to Evaluate Job Controls (Full Program)	All establishments with problem jobs	2-16 hours of employee and 2-32 hours of managerial time, depending on problem job; in 15% of cases, $2,000 for consulting ergonomist's time is assumed to be required	Manager with full program training
Cost to Administer MSD Management (Full Program)	All establishments with problem jobs	1 hour of managerial time per MSD	In 85% of cases, manager with full program training; in 15% of cases, consultant ergonomist.
Cost to Do Record-keeping (Full Program	All establishments with an MSD or persistent symptoms	0.25 hour of supervisory time per MSD	Supervisor
Cost to Conduct Program Evaluation (Full Program)	All establishments with full program	4 hours of managerial time in the three years following occurrence of covered MSD. For 25% of problem jobs able to use quick fix option, no program evaluation is conducted.	Manager with full program training
Cost to Implement Job Controls -- Engineering, work practice, or dministrative controls	Job control costs: all establishments with problem jobs	Costs per job intervention per affected employee vary by industry and occupational groups and are presented in detail in Tables V-9 to V-13 (affected employees include the employee incurring the covered MSD and all other employees in the establishment with the same job)	Covered under costs calculated for evaluating and implementing controls (above)
Cost to Provide Work Restriction Protection	All establishments with problem jobs	$1,293 per MSD	Covered in costs for administering MSD management, above

APPENDIX B

OPTIONS CALCULATION

The calculation method for valuing real-option illustrated here consists of the Black-Scholes formula and the binomial lattice methods. Both methods will be shown as follows.

B.1 The Black-Scholes Formula

This methodology uses only five inputs into one equation and gives out the value of an European call or put option with no dividend. This method is limited only to value single future investment.

V_{Call} = $N(d_1)A - N(d_2)X_1e^{-rT}$

V_{Put} = $[N(d_1) - 1]*A_t + e^{-rT} *X_2*[1-N(d_2)]$

V_{Put} = Value of put option

V_{Call} = Current value of call option

A = Current value of the underlying asset

X_1 = Cost of investment

X_2 = Future value if equipment is sold

r = Risk-free rate of return

T = Time to expiration

σ = Volatility of the underlying asset

$N(d_1)$ and $N(d_2)$ are the value of the normal distribution at d_1 and d_2

d_1 = $[\ln(A/X) + (r + 0.5\sigma^2)T] / \sigma\sqrt{T}$

d_2 = $d_1 - \sigma\sqrt{T}$

B.2 The Binomial Lattice Modal

The binomial lattice method is a deterministic model that is one of the most widely used methods to value options introduced by John Cox, Stephen Ross and Mark Rubinstein. Binomial is a discrete time model which divides time into discrete points and only tries to model a price at these times, as opposed to a continuous time model (Black Sholes). The reason for its application is that the binomial method can price any type of options including European and American options with or without dividend. Even the case of a non-constant volatility stock or a non-constant variance of underlying asset movement can be calculated using the binomial tree method. This is very important since real options are usually complex investment problems, where the normal Black Sholes analytical formula for valuing European Call/Put options may not be able to value such complex real options.

Real options applications are mostly similar to American Call/Put options with dividend. It is not possible to price them using Black Sholes method. Using the binomial method to price options can be divided into two parts. First is the modeling of the stock price or any underlying asset, such as the benefits gained through ergonomics interventions. Second is to price option value through backward induction.

B.2.1 Modeling Stock Price

There are two types of binomial trees: the standard tree introduced by Cox-Ross-Rubinstein where the model allows only constant volatility, and the flexible tree that allow variable volatility, which is more appropriate for pricing/valuing real options applications since the volatility of physical assets are not constant. While standard tree assumes a constant volatility no matter what price path the stock or project takes, a flexible tree allows volatility to change with time and spot price at each path. Building a stock price movement or future cash inflow begins with a starting time of the tree (initial time) and ends with a terminal time. The model identifies the value at each period between the initial time and the terminal time. The number of time periods between these two points can be divided into as many time-periods as are required. The price at each time-period starts at the initial time and either moves up or move down to the next time-period based on its volatility and probability until the end terminal time is met.

Let S be the value of stock at time t. The stock price will either rise to S_u or fall to S_d at time t with the probability p if stock moves up to S_u, and probability (1-p) if stock S moves down to S_d. The up-ratio "u" = S_u/S and the down-ratio "d", is given by d = S_d/S. Figure A1 illustrates such stock movements.

Using binomial models all possible cash inflows from the project or stock price are spelled out ahead of time. For the standard tree the up and down ratio as well as the transition probability are the same at every node. All standard trees are recombining, which means that, if the up-ratio is u and down-ratio is d, then an upward move followed by a downward move is equal to a downward move followed by an upward move (ud = du).

For a flexible tree the upward ratio and the transition probability at each node do not have to be the same. But the tree still has to be recombined (ud = du). However, flexible trees have fewer restrictions than standard trees. They will be useful in modeling real options applications since the uncertainty in cash flow is not path dependent. That volatility can change because of the changes in management decisions related to the project. Such management decisions include but are not limited to the decision to defer or accelerate the timing of project implementation as well as the expansion and reduction of the project's output based on future outcome.

To build a standard tree we need to determine the number of time period N for the amount of time between the initial time t_0 and the terminal time t_i.

So that $\Delta t = T/N$

Let μ be the expected value of the return of the project. In order to build a binomial tree we need a formula for u and p so that the model has expected return μ and standard deviation σ. Cox-Ross-Rubinstein introduced a formula for u, d and p as follows:

$u = e^{\sigma}$ and $d = e^{-\sigma}$

$p = (e^r - d)/(u - d)$

Such a formula makes the expected value of return exactly equal to μ, and the volatility between each node (local volatility) equal to σ. The objective of using a binomial tree is to identify the risk-neutral transition probability, which is the probability that ensures the expected value to equal to the growth rate of the stock at the risk-free rates. The risk-free rate is the interest rate on which bonds of all maturities can be bought and sold in any amount. One assumes that one can always borrow and lend at the risk-free rate of interest. Assume r is the risk-free rate, the expected value of stock is equal to its forward price one period later.

$pS_u + (1-p)S_d = e^r S \implies p = (e^r S - S_d)/(S_u - S_d)$

p is the risk-neutral probability that is calculated based on the risk-free rate and the values S_u, S_d and S. The calculation of transition probability is needed at every node when modeling the flexible tree since each node in a flexible tree has different transition probability, as opposed to that of a standard tree.

In real options application, such as deferring an investment to gain more understanding of the future uncertainty, the monetary loss by deferring is analogous to a dividend on stock. Stock that pays dividends will lose value after the dividends are paid at the dividend date. Such dividends can be paid as a percentage of the stock price or a percentage of the estimated cash inflow of the project. Dividends can also be paid by fixed dollar amount similar to the way medical expenses, paid out by not implementing projects, can be estimated in dollar amounts. Assume that at time t_{i+1} is the ex-dividend date. On this date, a dividend of q percent of stock value at time t_{i+1} will be paid. The stock price at time t_{i+1} will drop from St_{i+1} to St_{i+1} (1-q).

B.2.2 Pricing Option with Binomial Tree

This section shows how to use binomial tree model of stock price movement to price European Call and Put options. Almost any kind of option can be priced on a binomial tree. The methods for pricing options are the same for both the standard tree and the flexible tree. The steps consist of, first building a binomial tree (standard/flexible), and second pricing options through a backward induction process.

Even though the Black-Scholes formula is an easy-to-use analytical solution, some researchers suggested the binomial method, which can solve other types of investment. The binomial method uses the idea that assets have uncertain future values. Asset can take only one of two possible values, which are to move upward or downward. Assume the asset has initial value A at the present time, and with a short period of time it will move up to Au or down to Ad. The multipliers to future value are u and d for upward and downward movement respectively. Also, in the succeeding period the possible value of assets will continue moving to Au^2, Aud or Au^2 to complete the binomial tree shown in Table B.1.

When a risk neutral approach is applied to the binomial modal, the expected return of the asset is the risk-free interest rate with constant volatility σ until the end of the period. The expected return for each period is

$[pAu + (1\text{-}p)Ad] / A = e^r$

where p is called the risk-neutral probability with the variance of return to be

$\sigma^2 = pu^2 + (1\text{-}p)d^2 - [pu + (1\text{-}p)d]^2$

or $\quad p = (e^r\text{-}d)/(u\text{-}d)$

In order to develop the binomial tree all, one needs is to find the value of multiplier u and d from the formula below.

$u = e^{\sigma}$ and $\quad d = e^{-\sigma}$

Table B.1 The possible benefit model

0	1	2	3	4
A0	A11 = Au	A12 =A11*u	A13 =A12*u	A14= A13*u
	A21 =Ad	A22 =A21*u	A23 =A22*u	A24=A23*u
		A32 =A21*d	A33 =A32*u	A34=A33*u
			A43 =A32*d	A44=A43*u
				A54 = A43*d

In finding the value of the option, one needs to back trace the predicted binomial tree to the initial period in order to achieve the value of the option. This is done by what is called "folding back the values" from the end period, as seen in Figure B.2. But first one needs to identify the end period value, which can be found from the function max[X-A_{mn},0].

B14 = max[X-A14,0], B24,…. , B54 = max[X-A54,0]

Where X is the investment cost, for other values of B can be found from the formula. B0 will be the value of the option at the present time, (Kulatilaka 1999).

$B43 = [B44*p + B54*(1-p)]/e^r$

$B33 = [B34*p + B44*(1-p)]/e^r$

…………………

$B11 = [B12*p + B22*(1-p)]/e^r$

$B0 = [B11*p + B21*(1-p)]/e^r$

Table B.2 The option value calculation

0	1	2	3	4
B0	B11	B12	B13	B14
	B21	B22	B23	B24
		B32	B33	B34
			B43	B44
				B54

A Binomial based on an American call options valuation approach is used for valuing the optimum timing of investment. The method is slightly different in finding the B value of period T-1.

$Max[X-A_{mn}, B_{mn} = [B_{m(n+1)}*p + B_{(m+1)(n+1)}*(1-p)]/e^r]$

APPENDIX C

DETAILED CALCULATION FOR ERGONOMICS PROGRAM VALUATION

C.1 MSD Related Costs Estimate

Table C.1 to C.4 shows the result of the potential costs related to MSD problems that can occur over a six-year period for the selected SIC.

Table C.1 Estimated potential **workers compensation** cost that may occur as a result of MSD injuries for the selected SIC.

SIC	Year1	Year2	Year3	Year4	Year5	Year6
2011	$25,352	$21,998	$18,564	$15,050	$11,457	$7,784
3711	$54,071	$54,551	$55,030	$55,510	$55,990	$56,470
2015	$71,463	$61,907	$52,124	$42,115	$31,881	$21,420
2325	$29,905	$27,742	$25,495	$23,166	$20,752	$18,256
3143	$21,333	$21,585	$21,838	$22,090	$22,343	$22,595
3633	$75,584	$76,360	$77,136	$77,912	$78,688	$79,464
3632	$68,773	$66,825	$64,801	$62,699	$60,521	$58,265
3465	$21,230	$21,458	$21,686	$21,913	$22,141	$22,369
3694	$12,365	$12,491	$12,616	$12,742	$12,867	$12,993
3714	$22,680	$22,175	$21,662	$21,141	$20,611	$20,073
3639	$65,970	$66,737	$67,505	$68,272	$69,040	$69,807
2013	$18,358	$17,604	$16,835	$16,053	$15,256	$14,446
375	$18,805	$16,742	$14,625	$12,453	$10,227	$7,947
2254	$62,811	$44,911	$26,661	$8,063	$8,063	$8,063
2326	$46,028	$40,734	$35,301	$29,730	$24,021	$18,174

Table C.2 Estimated potential **work-related** cost that may occur as a result of MSD injuries for the selected SIC.

SIC	Year1	Year2	Year3	Year4	Year5	Year6
2011	$9,116	$7,825	$6,535	$5,244	$3,953	$2,663
3711	$5,663	$5,663	$5,663	$5,663	$5,663	$5,663
2015	$28,881	$24,747	$20,612	$16,477	$12,342	$8,207
2325	$1,518	$1,380	$1,242	$1,105	$967	$829
3143	$924	$924	$924	$924	$924	$924
3633	$15,977	$15,977	$15,977	$15,977	$15,977	$15,977
3632	$11,346	$10,875	$10,403	$9,932	$9,461	$8,990
3465	$1,671	$1,671	$1,671	$1,671	$1,671	$1,671
3694	$1,461	$1,461	$1,461	$1,461	$1,461	$1,461
3714	$3,191	$3,098	$3,005	$2,912	$2,820	$2,727
3639	$4,263	$4,263	$4,263	$4,263	$4,263	$4,263
2013	$1,773	$1,688	$1,604	$1,519	$1,435	$1,350
375	$1,395	$1,222	$1,050	$878	$706	$534
2254	$12,213	$8,694	$5,174	$1,655	$1,655	$1,655
2326	$1,817	$1,588	$1,358	$1,128	$899	$669

Table C3 Estimated potential **labor turnover** cost that may occur as a result of MSD injuries for the selected SIC.

SIC	Year1	Year2	Year3	Year4	Year5	Year6
2011	$1,337	$1,147	$957	$767	$577	$388
3711	$600	$600	$600	$600	$600	$600
2015	$4,206	$3,604	$3,001	$2,399	$1,797	$1,194
2325	$408	$374	$341	$308	$274	$241
3143	$250	$250	$250	$250	$250	$250
3633	$1,960	$1,960	$1,960	$1,960	$1,960	$1,960
3632	$1,434	$1,379	$1,325	$1,270	$1,216	$1,162
3465	$222	$222	$222	$222	$222	$222
3694	$186	$186	$186	$186	$186	$186
3714	$302	$292	$282	$272	$262	$252
3639	$717	$717	$717	$717	$717	$717
2013	$327	$309	$292	$274	$257	$239
375	$169	$149	$130	$110	$91	$71
2254	$2,044	$1,444	$844	$244	$244	$244
2326	$550	$482	$413	$344	$276	$207

Table C4 Estimated **total potential cost** that may occur as a result of MSD injuries for the selected SIC.

SIC	Year1	Year2	Year3	Year4	Year5	Year6
2011	$35,805	$30,971	$26,056	$21,062	$15,988	$10,834
3711	$60,334	$60,813	$61,293	$61,773	$62,252	$62,732
2015	$104,551	$90,257	$75,737	$60,991	$46,019	$30,822
2325	$31,830	$29,496	$27,079	$24,578	$21,994	$19,326
3143	$22,508	$22,760	$23,012	$23,265	$23,517	$23,770
3633	$93,522	$94,298	$95,073	$95,849	$96,625	$97,401
3632	$81,552	$79,079	$76,529	$73,902	$71,198	$68,417
3465	$23,123	$23,350	$23,578	$23,806	$24,034	$24,262
3694	$14,012	$14,138	$14,263	$14,389	$14,514	$14,640
3714	$26,173	$25,565	$24,949	$24,325	$23,692	$23,052
3639	$70,950	$71,718	$72,485	$73,253	$74,020	$74,788
2013	$20,458	$19,601	$18,731	$17,846	$16,948	$16,036
375	$20,368	$18,113	$15,805	$13,442	$11,024	$8,552
2254	$77,067	$55,048	$32,680	$9,962	($13,104)	($36,519)
2326	$48,396	$42,803	$37,072	$31,203	$25,196	$19,050

C.2 Ergonomics Program Valuation at Various Discount Rates

Table C.5 Estimated project value using the net present valuation method that may occur in order to implement ergonomics program (with *Ergo checklist* as analysis method) to reduce MSD injuries for the selected SIC in the top quartile. Assume interest rate is *10%*.

SIC	Ergonomics program effective rate (%)						
	20	30	40	50	60	70	80
2011	$ (239,763)	$ (69,641)	$ 100,480	$ 270,602	$ 440,724	$610,846	$780,967
3711	$ 343,109	$ 905,898	$ 1,468,687	$ 2,031,477	$ 2,594,266	$3,157,055	$3,719,845
2015	$ (182,725)	$ (89,465)	$ 3,796	$ 97,056	$ 190,317	$283,577	$376,838
2325	$ (28,549)	$ 15,208	$ 58,964	$ 102,721	$ 146,477	$190,234	$233,990
3143	$ (11,035)	$ 24,337	$ 59,708	$ 95,080	$ 130,451	$165,823	$201,194
3633	$ (291,995)	$ (110,985)	$ 70,025	$ 251,035	$ 432,045	$613,055	$794,065
3632	$ (94,714)	$ 58,595	$ 211,904	$ 365,213	$ 518,522	$671,831	$825,140
3465	$ 31,621	$ 75,138	$ 118,655	$ 162,173	$ 205,690	$249,207	$292,725
3694	$ 10,321	$ 41,693	$ 73,065	$ 104,437	$ 135,808	$167,180	$198,552
3714	$ 10,287	$ 78,486	$ 146,684	$ 214,883	$ 283,082	$351,280	$419,479
3639	$ 78,256	$ 217,228	$ 356,199	$ 495,171	$ 634,143	$773,114	$912,086
2013	$ 9,117	$ 40,688	$ 72,259	$ 103,830	$ 135,401	$166,973	$198,544
375	$ 35,192	$ 107,210	$ 179,227	$ 251,245	$ 323,263	$395,281	$467,299
2254	$ (316,442)	$ (236,630)	$ (156,819)	$ (77,007)	$ 2,804	$82,616	$162,428
2326	$ (8,672)	$ 18,325	$ 45,323	$ 72,321	$ 99,319	$126,317	$153,314

Table C.6 Estimated project value using the net present valuation method that may occur in order to implement ergonomics program (with *Ergo detailed* as analysis method) to reduce MSD injuries for the selected SIC in the top quartile. Assume interest rate is *10%*.

SIC	Ergonomics program effective rate (%)						
	20	30	40	50	60	70	80
2011	$ (434,016)	$ (263,894)	$ (93,772)	$ 76,349	$ 246,471	$416,593	$586,715
3711	$ 106,840	$ 669,629	$ 1,232,419	$ 1,795,208	$ 2,357,997	$2,920,787	$3,483,576
2015	$ (295,651)	$ (202,390)	$ (109,130)	$ (15,869)	$ 77,391	$170,652	$263,912
2325	$ (44,763)	$ (1,006)	$ 42,750	$ 86,507	$ 130,263	$174,020	$217,776
3143	$ (21,221)	$ 14,151	$ 49,522	$ 84,894	$ 120,265	$155,637	$191,008
3633	$ (416,043)	$ (235,033)	$ (54,023)	$ 126,987	$ 307,997	$489,007	$670,017
3632	$ (194,327)	$ (41,018)	$ 112,291	$ 265,600	$ 418,909	$572,218	$725,527
3465	$ 16,538	$ 60,055	$ 103,573	$ 147,090	$ 190,607	$234,125	$277,642
3694	$ (3,398)	$ 27,973	$ 59,345	$ 90,717	$ 122,089	$153,460	$184,832
3714	$ (26,163)	$ 42,035	$ 110,234	$ 178,433	$ 246,631	$314,830	$383,029
3639	$ 25,511	$ 164,482	$ 303,454	$ 442,426	$ 581,397	$720,369	$859,341
2013	$ (5,313)	$ 26,258	$ 57,829	$ 89,401	$ 120,972	$152,543	$184,114
375	$ 3,721	$ 75,739	$ 147,757	$ 219,775	$ 291,793	$363,811	$435,829
2254	$ (393,559)	$ (313,748)	$ (233,936)	$ (154,125)	$ (74,313)	$5,499	$85,310
2326	$ (17,855)	$ 9,143	$ 36,141	$ 63,138	$ 90,136	$117,134	$144,132

Table C.7 Estimated project value using the net present valuation method that may occur in order to implement ergonomics program (with *Ergo checklist* as analysis method) to reduce MSD injuries for the selected SIC in the top quartile. Assume interest rate is *15%*.

SIC	20	30	40	50	60	70	80
2011	($209,050)	($57,834)	$93,382	$244,598	$395,815	$547,031	$698,247
3711	$274,941	$767,427	$1,259,914	$1,752,401	$2,244,887	$2,737,374	$3,229,861
2015	($162,131)	($79,216)	$3,700	$86,615	$169,531	$252,446	$335,362
2325	($26,951)	$11,644	$50,239	$88,834	$127,428	$166,023	$204,618
3143	($12,259)	$18,686	$49,632	$80,577	$111,522	$142,467	$173,413
3633	($269,049)	($110,652)	$47,746	$206,143	$364,541	$522,939	$681,336
3632	($96,530)	$38,083	$172,697	$307,310	$441,923	$576,537	$711,150
3465	$25,236	$63,312	$101,387	$139,463	$177,539	$215,614	$253,690
3694	$6,677	$34,128	$61,579	$89,030	$116,481	$143,932	$171,383
3714	$5,033	$64,872	$124,711	$184,550	$244,389	$304,228	$364,067
3639	$61,522	$183,107	$304,692	$426,276	$547,861	$669,446	$791,031
2013	$6,876	$34,626	$62,377	$90,128	$117,879	$145,629	$173,380
375	$29,153	$92,957	$156,762	$220,566	$284,370	$348,174	$411,978
2254	($273,788)	($201,381)	($128,974)	($56,567)	$15,840	$88,247	$160,654
2326	($8,124)	$15,811	$39,746	$63,681	$87,616	$111,551	$135,487

Table C.8 Estimated project value using the net present valuation method that may occur in order to implement ergonomics program (with *Ergo detailed* as analysis method) to reduce MSD injuries for the selected SIC in the top quartile (Excluding over exertion lifting; Exposure code 221). Assume interest rate is *15%*.

SIC	20	30	40	50	60	70	80
2011	($386,778)	($235,562)	($84,346)	$66,870	$218,086	$369,302	$520,518
3711	$58,771	$551,257	$1,043,744	$1,536,231	$2,028,717	$2,521,204	$3,013,690
2015	($265,451)	($182,535)	($99,620)	($16,704)	$66,211	$149,127	$232,042
2325	($41,785)	($3,191)	$35,404	$73,999	$112,593	$151,188	$189,783
3143	($21,578)	$9,367	$40,312	$71,257	$102,203	$133,148	$164,093
3633	($382,545)	($224,147)	($65,750)	$92,648	$251,045	$409,443	$567,840
3632	($187,669)	($53,056)	$81,557	$216,170	$350,784	$485,397	$620,010
3465	$11,436	$49,512	$87,588	$125,663	$163,739	$201,815	$239,890
3694	($5,876)	$21,575	$49,026	$76,477	$103,928	$131,379	$158,830
3714	($28,317)	$31,522	$91,361	$151,200	$211,039	$270,878	$330,717
3639	$13,264	$134,848	$256,433	$378,018	$499,603	$621,187	$742,772
2013	($6,327)	$21,424	$49,175	$76,926	$104,676	$132,427	$160,178
375	$360	$64,164	$127,968	$191,772	$255,576	$319,381	$383,185
2254	($344,345)	($271,938)	($199,531)	($127,124)	($54,717)	$17,690	$90,097
2326	($16,525)	$7,410	$31,345	$55,280	$79,215	$103,150	$127,085

C.3 Real Option Analysis

Table C.9 The increase in project's value when management flexibility is under consideration (A&E = 1.58).

SIC	NPV	A&E	ENPV	Increase in project value
2011	$ (4,439)	$ 66,932	$62,493	-14.08
3711	$1,412,247	$ 655,022	$2,067,269	1.46
2015	$(19,290)	$ 33,516	$14,226	-0.74
2325	$53,681	$ 43,396	$97,077	1.81
3143	$72,413	$ 45,454	$117,867	1.63
3633	$163,164	$ 119,467	$282,631	1.73
3632	$286,959	$ 134,789	$421,748	1.47
3465	$118,018	$ 54,670	$172,688	1.46
3694	$81,416	$ 36,044	$117,460	1.44
3714	$148,192	$ 68,742	$216,934	1.46
3639	$357,665	$ 168,287	$525,952	1.47
2013	$65,476	$ 33,806	$99,282	1.52
375	$130,392	$ 73,900	$204,292	1.57
2254	$(252,350)	$ 18	($252,332)	1.00
2326	$29,571	$ 26,097	$55,668	1.88

Table C.10 The increase in project's value when management flexibility is under consideration (A&R = 1.32).

SIC	NPV	A&R	ENPV	Increase in project value
2011	$ (4,439)	$ 85,715	$81,276	-18.31
3711	$1,412,247	$ 339,875	$1,752,122	1.24
2015	$(19,290)	$ 46,001	$26,711	-1.38
2325	$53,681	$ 22,221	$75,902	1.41
3143	$72,413	$ 20,181	$92,594	1.28
3633	$163,164	$ 74,275	$237,439	1.46
3632	$286,959	$ 93,757	$380,716	1.33
3465	$118,018	$ 26,546	$144,564	1.22
3694	$81,416	$ 19,076	$100,492	1.23
3714	$148,192	$ 41,881	$190,073	1.28
3639	$357,665	$ 83,598	$441,263	1.23
2013	$65,476	$ 19,507	$84,983	1.30
375	$130,392	$ 47,901	$178,293	1.37
2254	$(252,350)	$ 173	($252,177)	1.00
2326	$29,571	$ 14,122	$43,693	1.48

Table C.11 The increase in project's value when management flexibility is under consideration (E&R = 1.17).

SIC	NPV	E&R	ENPV	Increase in project value
2011	$ (4,439)	$ 1,786	($2,653)	0.60
3711	$1,412,247	$ 220,623	$1,632,870	1.16
2015	$(19,290)	$ 764	($18,526)	0.96
2325	$53,681	$ 13,993	$67,674	1.26
3143	$72,413	$ 19,072	$91,485	1.26
3633	$163,164	$ 30,624	$193,788	1.19
3632	$286,959	$ 23,527	$310,486	1.08
3465	$118,018	$ 20,566	$138,584	1.17
3694	$81,416	$ 11,760	$93,176	1.14
3714	$148,192	$ 16,603	$164,795	1.11
3639	$357,665	$ 60,797	$418,462	1.17
2013	$65,476	$ 9,109	$74,585	1.14
375	$130,392	$ 13,836	$144,228	1.11
2254	$(252,350)	$ 932	($251,418)	1.00
2326	$29,571	$ 7,339	$36,910	1.25

Table C.12 The increase in project's value when management flexibility is under consideration (A = 1.32).

SIC	NPV	A	ENPV	Increase in project value
2011	$ (4,439)	$125,123	$120,684	-27.19
3711	$1,412,247	$339,871	$1,752,118	1.24
2015	$(19,290)	$33,243	$13,953	-0.72
2325	$53,681	$22,210	$75,891	1.41
3143	$72,413	$20,181	$92,594	1.28
3633	$163,164	$74,073	$237,237	1.45
3632	$286,959	$93,468	$380,427	1.33
3465	$118,018	$26,546	$144,564	1.22
3694	$81,416	$19,074	$100,490	1.23
3714	$148,192	$41,870	$190,062	1.28
3639	$357,665	$83,597	$441,262	1.23
2013	$65,476	$19,493	$84,969	1.30
375	$130,392	$47,855	$178,247	1.37
2254	$(252,350)	$18	($252,332)	1.00
2326	$29,571	$14,110	$43,681	1.48

Table C.13 The increase in project's value when management flexibility is under consideration (E = 1.17).

SIC	NPV	E	ENPV	Increase in project value
2011	$ (4,439)	$276	($4,163)	0.94
3711	$1,412,247	$220,601	$1,632,848	1.16
2015	$(19,290)	$86	($19,204)	1.00
2325	$53,681	$13,971	$67,652	1.26
3143	$72,413	$19,072	$91,485	1.26
3633	$163,164	$30,315	$193,479	1.19
3632	$286,959	$23,167	$310,126	1.08
3465	$118,018	$20,566	$138,584	1.17
3694	$81,416	$11,757	$93,173	1.14
3714	$148,192	$16,572	$164,764	1.11
3639	$357,665	$60,793	$418,458	1.17
2013	$65,476	$9,087	$74,563	1.14
375	$130,392	$13,780	$144,172	1.11
2254	$(252,350)	$1	($252,349)	1.00
2326	$29,571	$7,320	$36,891	1.25

Table C14 The increase in project's value when management flexibility is under consideration (R = 0).

SIC	NPV	R	ENPV	Increase in project value
2011	$ (4,439)	$25,423	$20,984	-5.73
3711	$1,412,247	$23	$1,412,270	0.00
2015	$(19,290)	$16,617	($2,673)	-0.86
2325	$53,681	$23	$53,704	0.00
3143	$72,413	$0	$72,413	0.00
3633	$163,164	$412	$163,576	0.00
3632	$286,959	$479	$287,438	0.00
3465	$118,018	$0	$118,018	0.00
3694	$81,416	$3	$81,419	0.00
3714	$148,192	$34	$148,226	0.00
3639	$357,665	$4	$357,669	0.00
2013	$65,476	$24	$65,500	0.00
375	$130,392	$63	$130,455	0.00
2254	$(252,350)	$25,619	($226,731)	-0.10
2326	$29,571	$20	$29,591	0.00

APPENDIX D

DATABASE STRUCTURE

The study focused on estimating the costs and benefits of an ergonomics program for a particular SIC. Therefore, the data collected must be identified uniquely by their SIC codes. The SIC table contains the SIC codes and their description and it is linked to the Exposure Rate Table which contains the information related to the incidence rate for each exposure type (over-exertion, over-exertion in lifting, repetitive motion and bodily reaction) for a particular SIC. The Exposure Rate Table is also linked with the Exposure Table that defines the exposure description, the average days away from work due to such exposure and the rate of exposure over 31 days. The number of MSD cases for a selected SIC is estimated using a regression function based on the Function Exposure Table. The Function Exposure Table contains the intercept, slope, and the r-square that will estimate the potential injury cases that may occur for a specified number of years.

Later the number of injury cases are used for estimating the number of illness cases in each illness types. Exposure_Illness_Percentage query table contains the coefficient that is used for estimating the number of illness cases for a particular illness type that is related to the exposure cases. The illness cases for a six-year time frame are estimated in the sets of query table name "Illness" followed by an underscore and the exposure name. The medical expenses are estimated using the Function_MedicalCost table that contains the intercept and slope.

The total medical costs for a particular exposure type is calculated and stored in the Sum_MedicalCost followed by underscore and the exposure name. The temporary disability payment (TDP) for each illness type is in a table called TDP follow by underscore exposure name such as TDP_RepetitiveMotion, while the total costs of TDP for that particular exposure is in another table called Sum_TDP underscore the exposure name such as Sum_TDP_RepetitiveMotion. Later, the costs of PDP is calculated based on the total TDP costs and stored in the PDP underscore exposure name such as PDP_RepetitiveMotion.

D.1 Table Structures

1. CCS (CCS_Code, CCS_Descript): Contain CCS code and their description.
2. DRG (DRG_Code, DRG_Descript): Contains DRG code and their description.
3. DRG1993 (DRG_Code, Total charges, Percent discharge, Average charges, Average LOS, Charge per day): MSD related information extracted from HCUP categorized by DRG in 1993.
4. DRG1994 (DRG_Code, Total cases, Percent discharge, Average charges, Average LOS, Charge per day): MSD related information extracted from HCUP categorized by DRG in 1994.
5. DRG1995 (DRG_Code, Total cases, Percent discharge, Average charges, Average LOS, Charge per day): MSD related information extracted from HCUP categorized by DRG in 1995.
6. DRG1996 (DRG_Code, Total cases, Percent discharged, Average charge, Average LOS, Charge per day): MSD related information extracted from HCUP categorized by DRG in 1996.

7. DRG_1997 (DRG_Code, Total cases, Percent discharged, Average charges, Average LOS, Charge per day): MSD related information extracted from HCUP categorized by DRG in 1997.
8. ErgoIntervention (S_Code, S_Description, CostPerWorker, SavingPerWorker, NetControlCost, SurplusLaborSaving): The table contain the scenario code that are assigned to the types of ergonomics control.
9. Exposure (Exposure_Code, Exposure_Desc, Exposure_Over31days97, Exposure_Over31days96, Exposure_Over31days95, Exposure_Over31days94, Exposure_Over31days93, Exposure_DaysAway97, Exposure_DaysAway96, Exposure_DaysAway95, Exposure_DaysAway94, Exposure_DaysAway93): Contains information related to the types of exposure such as the number of cases that involved days away from work over one month and cases with days away from work.
10. Ill_Exposure_Matrix (Illness_Code, Exposure_Code, percent97, percent96, percent95, percent94, percent93): Contains the EICM used for determining the proportion of illness cases within an exposure type.
11. Illness (Illness_Code, Illness_Descript, Illness_DaysAway97, Illness_DaysAway96, Illness_DaysAway95, Illness_DaysAway94, Illness_DaysAway93, Illness_Medical97, Illness_Medical96, Illness_Medical95, Illness_Medical94, Illness_Medical93): Contains information related to the nature of injury and illness such as the number of cases with days away from work and medical costs for each type of illness.

12. OCCGroup (OCC_Code, OCC_Group): Contains the categorization of occupational code into occupational group used in estimating the investments needed for ergonomics solution.
16. OCCGroup_SCode (OCC_Group, S_Code): Contains the occupational group categorization that maps with the scenario code. The table is used as linkage between occupational group and the cost of ergonomics solution grouped by the types of scenario assumptions.
17. Occupation (Occ_Descript, OCC_Code): Described the detailed occupational code.
18. OccupationGroup (OCC_Group, OCC_Group_Descript): Described detailed occupational group.
19. Provision (P_Code, Provision_Descript, Manager_Time, Employee_Time, ManagerPerMSD, EmployeePerMSD, CostPerMSD): Contains the information that triggers the costs of ergonomics program elements such as managers and workers time and wage.
20. SIC (SIC_Code, SIC_Description): Provides SIC code description.
21. SIC_AveEmp94 (SIC_Code, AveEmp): The average employee for each SIC in 1994.
22. SIC_AveEmp95 (SIC_Code, Ave_Emp): The average employee for each SIC in 1995
23. SIC_AveEmp96 (SIC_Code, AveEmp): The average employee for each SIC in 1996
24. SIC_AveEmp97 (SIC_Code, AveEmp): The average employee for each SIC in 1997
25. SIC_AveEmp98 (SIC_Code, AveEmp) The average employee for each SIC in 1998
26. SIC_Coeff94 (SIC_Code, RestrctCoeff, WithoutCoef): Restricted work coefficient
27. SIC_Coeff95 (SIC_Code, RestrictCoeff, WithoutCoeff): Restricted work coefficient
28. SIC_Coeff96 (SIC_Code, RestrictCoeff, WithoutCoeff): Restricted work coefficient

29. SIC_Coeff97 (SIC_Code, RestrictCoeff, WithoutCoeff): Restricted work coefficient
30. SIC_Coeff98 (SIC_Code, RestrictCoeff, WithoutCoeff): Restricted work coefficient
31. SIC_Exposure_Rate93 (SIC_Code, TotalCases, OverExertionTotal, OverExertionLifting, RepetitiveMotion): Incidence rate grouped by exposure types 1993
32. SIC_Exposure_Rate94 (SIC_Code, TotalCases, OverExertionTotal, OverExertionLifting, RepetitiveMotion): Incidence rate grouped by exposure types 1994
33. SIC_Exposure_Rate95 (SIC_Code, TotalCases, OverExertionTotal, OverExertionLifting, RepetitiveMotion): Incidence rate grouped by exposure types 1995
34. SIC_Exposure_Rate96 (SIC_Code, TotalCases, OverExertionTotal, OverExertionLifting, RepetitiveMotion): Incidence rate grouped by exposure types 1996
35. SIC_Exposure_Rate97 (SIC_Code, TotalCases, OverExertiontotal, OverExertionLifting, RepetitiveMotion): Incidence rate grouped by exposure types 1997

D.2 Database Tables and Queries

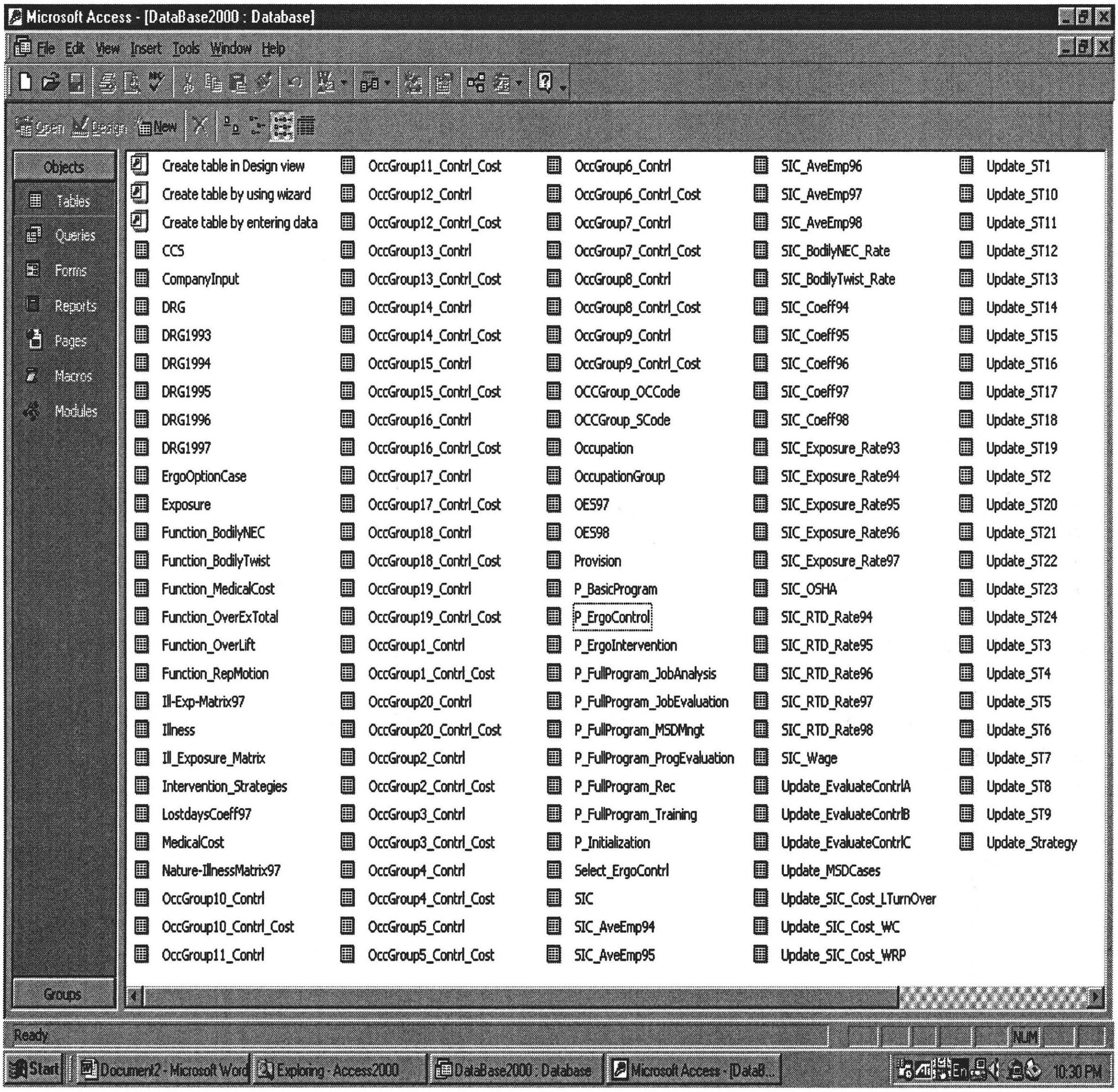

Figure D.2.1 Database Table

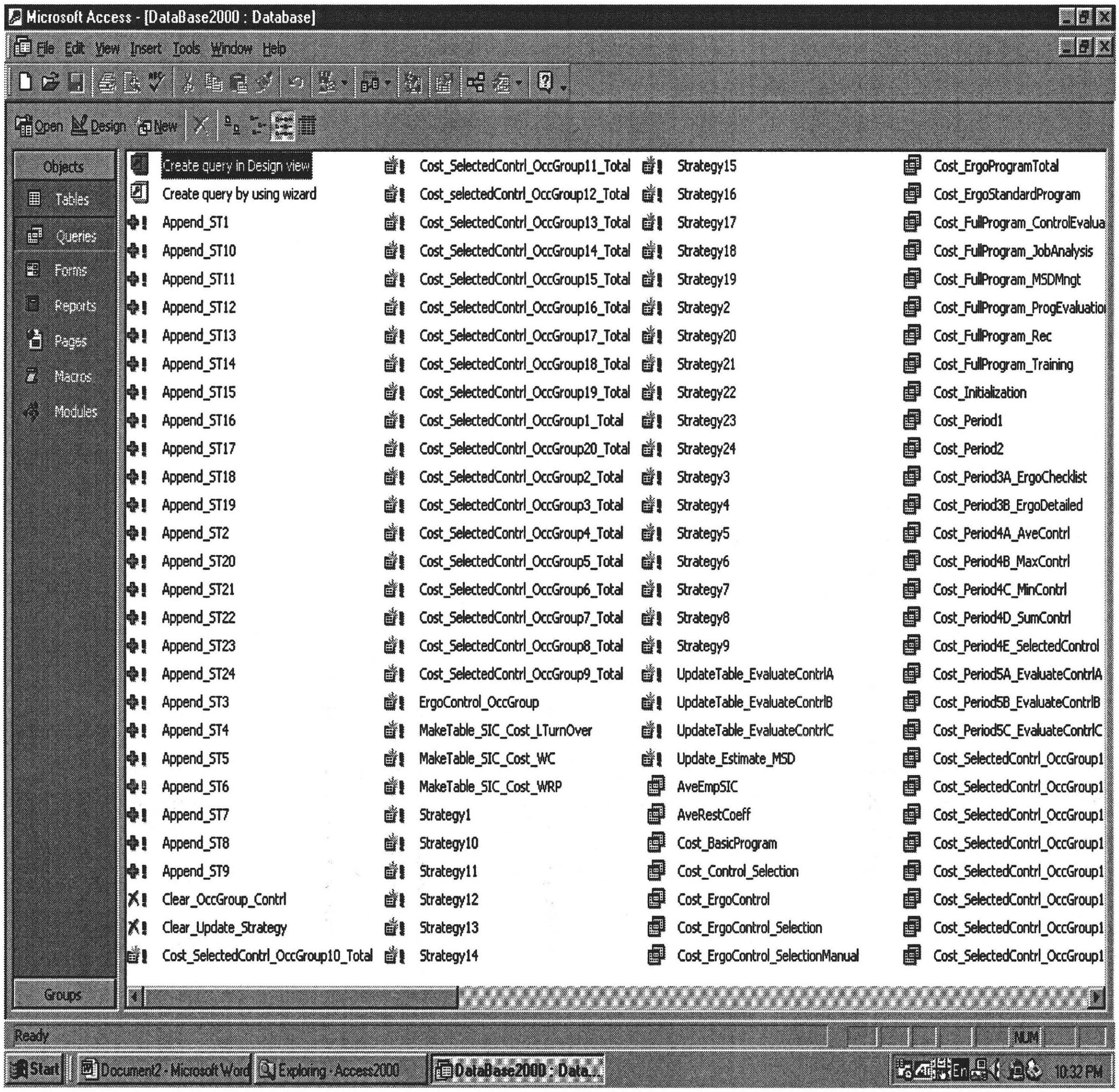

Figure D.2.2 Database Queries page 1

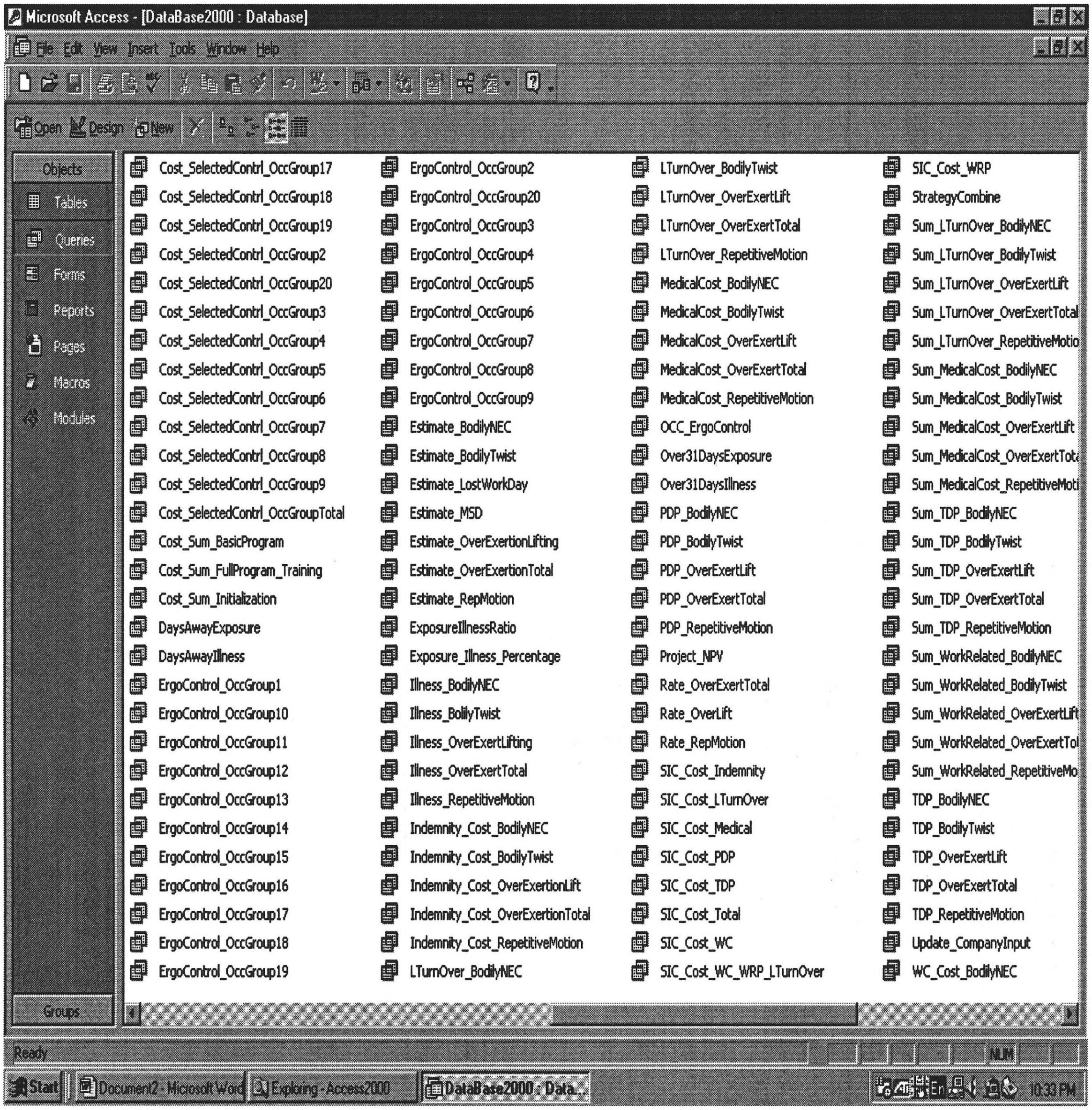

Figure D.2.3 Database Queries page 2

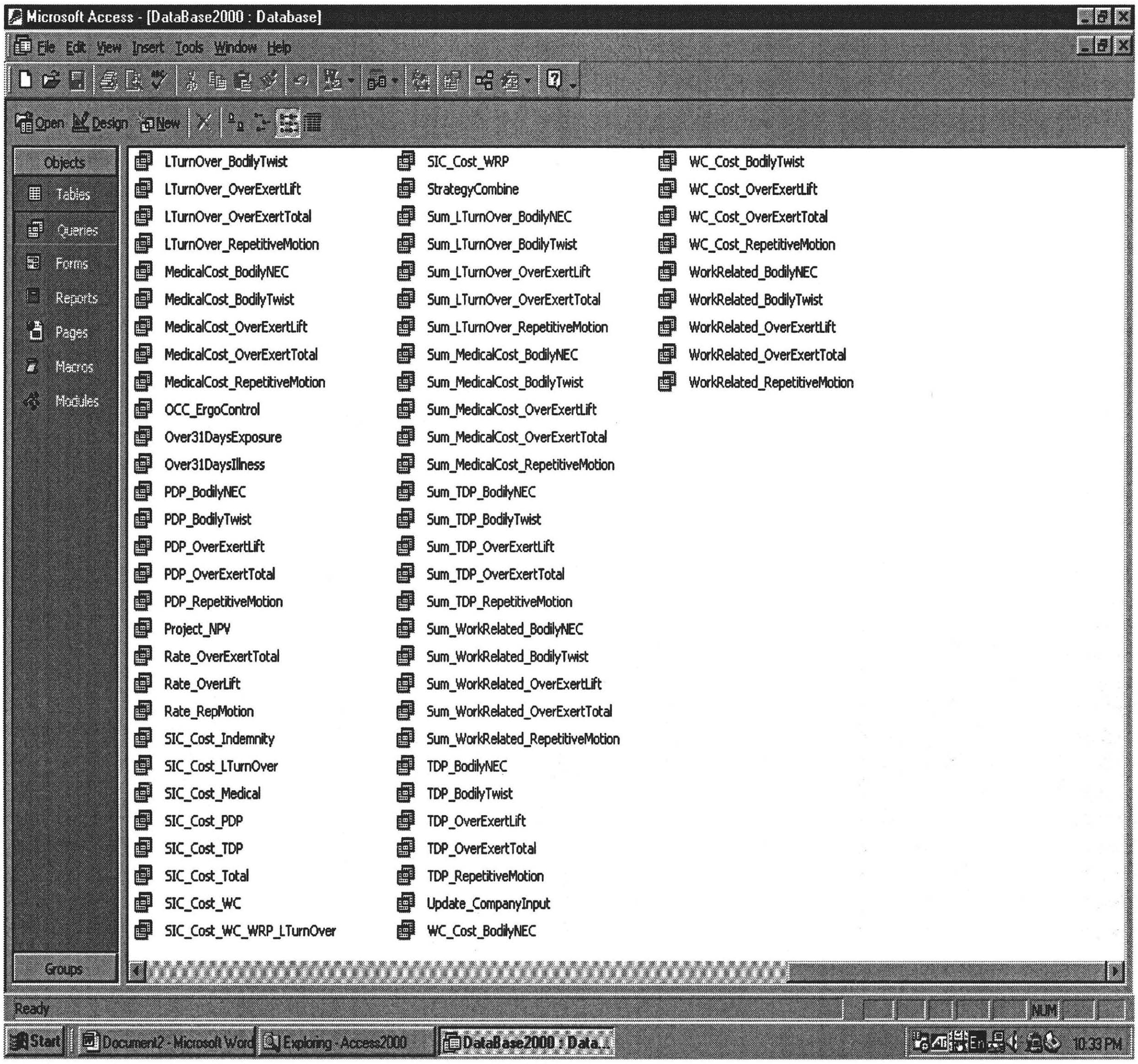

Figure D.2.4 Database queries page 3

D.3 SQL Code

D.3.1 Selected SQL Query Code for Estimate Potential Benefits or Cost Savings Query Code:

// Estimate MSD problem cases for the next six years

SELECT CompanyInput.SIC_Code, SIC.SIC_Description, CompanyInput.N_Year, CompanyInput.N_Emp, Function_BodilyNEC.Intercept, Function_BodilyNEC.Slope,
([Intercept]+[Slope]*([N_Year]-4))*[N_Emp]/10000 AS [Year 6],
([Intercept]+[Slope]*([N_Year]-5))*[N_Emp]/10000 AS [Year 5],
([Intercept]+[Slope]*([N_Year]-6))*[N_Emp]/10000 AS [Year 4],
([Intercept]+[Slope]*([N_Year]-7))*[N_Emp]/10000 AS [Year 3],

```
([Intercept]+[Slope]*([N_Year]-8))*[N_Emp]/10000 AS [Year 2],
([Intercept]+[Slope]*([N_Year]-9))*[N_Emp]/10000 AS [Year 1]
FROM (SIC INNER JOIN CompanyInput ON SIC.SIC_Code =
CompanyInput.SIC_Code) INNER JOIN Function_BodilyNEC ON (SIC.SIC_Code =
Function_BodilyNEC.SIC_Code) AND (CompanyInput.SIC_Code =
Function_BodilyNEC.SIC_Code);
```

// Estimate the proportion of MSD illness within each exposure type (bodily reaction)

```
SELECT Estimate_BodilyNEC.SIC_Code,
Exposure_Illness_Percentage.Exposure_Code,
Exposure_Illness_Percentage.Illness_Code,
Exposure_Illness_Percentage.Illness_Descript,
Exposure_Illness_Percentage.AvePercentage,
[AvePercentage]*[Estimate_BodilyNEC]![Year 6] AS [Year 6],
[AvePercentage]*[Estimate_BodilyNEC]![Year 5] AS [Year 5],
[AvePercentage]*[Estimate_BodilyNEC]![Year 4] AS [Year 4],
[AvePercentage]*[Estimate_BodilyNEC]![Year 3] AS [Year 3],
[AvePercentage]*[Estimate_BodilyNEC]![Year 2] AS [Year 2],
[AvePercentage]*[Estimate_BodilyNEC]![Year 1] AS [Year 1]

FROM Exposure_Illness_Percentage, CompanyInput INNER JOIN
Estimate_BodilyNEC ON CompanyInput.SIC_Code = Estimate_BodilyNEC.SIC_Code
WHERE (((Exposure_Illness_Percentage.Exposure_Code)="219") AND
((Exposure_Illness_Percentage.Illness_Code)="021" Or
(Exposure_Illness_Percentage.Illness_Code)="0972" Or
(Exposure_Illness_Percentage.Illness_Code)="1241" Or
(Exposure_Illness_Percentage.Illness_Code)="17" Or
(Exposure_Illness_Percentage.Illness_Code)="1734"));
```

// Estimate medical costs for each nature of illness within tthe type of exposure (bodily reaction)

```
SELECT Illness_BodilyNEC.SIC_Code, Illness_BodilyNEC.Exposure_Code,
Illness_BodilyNEC.Illness_Code, Illness_BodilyNEC.Illness_Descript,
Function_MedicalCost.Intercept_CCS, Function_MedicalCost.Slope_CCS,
Illness_BodilyNEC.[Year 6], [Year 6]*([Intercept_CCS]+6*[Slope_CCS]) AS
Year6_CCS, Illness_BodilyNEC.[Year 5], [Year 5]*([Intercept_CCS]+5*[Slope_CCS])
AS Year5_CCS, Illness_BodilyNEC.[Year 4], [Year
4]*([Intercept_CCS]+4*[Slope_CCS]) AS Year4_CCS, Illness_BodilyNEC.[Year 3],
[Year 3]*([Intercept_CCS]+3*[Slope_CCS]) AS Year3_CCS, Illness_BodilyNEC.[Year
2], [Year 2]*([Intercept_CCS]+2*[Slope_CCS]) AS Year2_CCS,
Illness_BodilyNEC.[Year 1], [Year 1]*([Intercept_CCS]+1*[Slope_CCS]) AS
Year1_CCS
FROM Function_MedicalCost INNER JOIN Illness_BodilyNEC ON
Function_MedicalCost.Illness_Code = Illness_BodilyNEC.Illness_Code;
```

// Estimate the costs of permanent disability payment for an exposure type

```
SELECT CompanyInput.SIC_Code, Sum_TDP_BodilyNEC.Exposure_Code,
CompanyInput.PDP_Ratio, Sum_TDP_BodilyNEC.[Sum Of Year6_TDP],
[PDP_Ratio]*[Sum Of Year6_TDP] AS Year6_PDP, Sum_TDP_BodilyNEC.[Sum Of
Year5_TDP], [PDP_Ratio]*[Sum Of Year5_TDP] AS Year5_PDP,
Sum_TDP_BodilyNEC.[Sum Of Year4_TDP], [PDP_Ratio]*[Sum Of Year4_TDP] AS
Year4_PDP, Sum_TDP_BodilyNEC.[Sum Of Year3_TDP], [PDP_Ratio]*[Sum Of
Year3_TDP] AS Year3_PDP, Sum_TDP_BodilyNEC.[Sum Of Year2_TDP],
[PDP_Ratio]*[Sum Of Year2_TDP] AS Year2_PDP, Sum_TDP_BodilyNEC.[Sum Of
Year1_TDP], [PDP_Ratio]*[Sum Of Year1_TDP] AS Year1_PDP
FROM CompanyInput INNER JOIN Sum_TDP_BodilyNEC ON
CompanyInput.SIC_Code = Sum_TDP_BodilyNEC.SIC_Code;
```

// Estimate the costs of temporary disability payment for an exposure type

```
SELECT CompanyInput.SIC_Code, Illness_BodilyNEC.Exposure_Code,
Illness_BodilyNEC.Illness_Descript, DaysAwayIllness.DaysAway,
SIC_Wage.Wage_Worker, Illness_BodilyNEC.[Year 6], [Year
6]*[DaysAway]*[Wage_Worker]*8 AS Year6_TDP, Illness_BodilyNEC.[Year 5], [Year
5]*[DaysAway]*[Wage_Worker]*8 AS Year5_TDP, Illness_BodilyNEC.[Year 4], [Year
4]*[DaysAway]*[Wage_Worker]*8 AS Year4_TDP, Illness_BodilyNEC.[Year 3], [Year
3]*[DaysAway]*[Wage_Worker]*8 AS Year3_TDP, Illness_BodilyNEC.[Year 2], [Year
2]*[DaysAway]*[Wage_Worker]*8 AS Year2_TDP, Illness_BodilyNEC.[Year 1], [Year
1]*[DaysAway]*[Wage_Worker]*8 AS Year1_TDP
FROM CompanyInput INNER JOIN SIC_Wage ON CompanyInput.SIC_Code =
SIC_Wage.SIC_Code, Illness_BodilyNEC INNER JOIN DaysAwayIllness ON
Illness_BodilyNEC.Illness_Code = DaysAwayIllness.Illness_Code;
```

// Estimate workers' compensation costs

```
SELECT CompanyInput.SIC_Code,
[Indemnity_Cost_BodilyNEC]![Year1]+[Sum_MedicalCost_BodilyNEC]![SumOfYear1
_CCS] AS Year1,
[Indemnity_Cost_BodilyNEC]![Year2]+[Sum_MedicalCost_BodilyNEC]![SumOfYear2
_CCS] AS Year2,
[Indemnity_Cost_BodilyNEC]![Year3]+[Sum_MedicalCost_BodilyNEC]![SumOfYear3
_CCS] AS Year3,
[Indemnity_Cost_BodilyNEC]![Year4]+[Sum_MedicalCost_BodilyNEC]![SumOfYear4
_CCS] AS Year4,
[Indemnity_Cost_BodilyNEC]![Year5]+[Sum_MedicalCost_BodilyNEC]![SumOfYear5
_CCS] AS Year5,
[Indemnity_Cost_BodilyNEC]![Year6]+[Sum_MedicalCost_BodilyNEC]![SumOfYear6
_CCS] AS Year6
FROM (CompanyInput INNER JOIN Indemnity_Cost_BodilyNEC ON
CompanyInput.SIC_Code = Indemnity_Cost_BodilyNEC.SIC_Code) INNER JOIN
```

```
Sum_MedicalCost_BodilyNEC ON CompanyInput.SIC_Code =
Sum_MedicalCost_BodilyNEC.SIC_Code;
```

// Estimate labor turnover costs

```
SELECT Illness_BodilyNEC.SIC_Code, Illness_BodilyNEC.Exposure_Code,
Illness_BodilyNEC.Illness_Descript, AveRestCoeff.AveRestCoeff,
Over31DaysExposure.[31DaysExpRatio], Over31DaysIllness.Ave31daysRatio,
CompanyInput.TurnOverRate, CompanyInput.HiringCost, Illness_BodilyNEC.[Year 6],
([Year 6]*[Ave31daysRatio]+[Year
6]*[AveRestCoeff]*[31DaysExpRatio])*[TurnOverRate]*[HiringCost] AS Year6_LT,
Illness_BodilyNEC.[Year 5], ([Year 5]*[Ave31daysRatio]+[Year
5]*[AveRestCoeff]*[31DaysExpRatio])*[TurnOverRate]*[HiringCost] AS Year5_LT,
Illness_BodilyNEC.[Year 4], ([Year 4]*[Ave31daysRatio]+[Year
4]*[AveRestCoeff]*[31DaysExpRatio])*[TurnOverRate]*[HiringCost] AS Year4_LT,
Illness_BodilyNEC.[Year 3], ([Year 3]*[Ave31daysRatio]+[Year
3]*[AveRestCoeff]*[31DaysExpRatio])*[TurnOverRate]*[HiringCost] AS Year3_LT,
Illness_BodilyNEC.[Year 2], ([Year 2]*[Ave31daysRatio]+[Year
2]*[AveRestCoeff]*[31DaysExpRatio])*[TurnOverRate]*[HiringCost] AS Year2_LT,
Illness_BodilyNEC.[Year 1], ([Year 1]*[Ave31daysRatio]+[Year
1]*[AveRestCoeff]*[31DaysExpRatio])*[TurnOverRate]*[HiringCost] AS Year1_LT
FROM ((AveRestCoeff INNER JOIN (CompanyInput INNER JOIN Illness_BodilyNEC
ON CompanyInput.SIC_Code = Illness_BodilyNEC.SIC_Code) ON
AveRestCoeff.SIC_Code = Illness_BodilyNEC.SIC_Code) INNER JOIN
Over31DaysExposure ON Illness_BodilyNEC.Exposure_Code =
Over31DaysExposure.Exposure_Code) INNER JOIN Over31DaysIllness ON
Illness_BodilyNEC.Illness_Code = Over31DaysIllness.Illness_Code;
```

// Estimate work-related costs

```
SELECT Illness_BodilyNEC.SIC_Code, Illness_BodilyNEC.Exposure_Code,
Illness_BodilyNEC.Illness_Descript, DaysAwayExposure.EstimatedDaysAway,
SIC_Wage.Wage_Worker, AveRestCoeff.AveRestCoeff, CompanyInput.WRP,
Illness_BodilyNEC.[Year 6], [Year
6]*[AveRestCoeff]*[EstimatedDaysAway]*[WRP]*[Wage_Worker]*8 AS Year6_WRP,
Illness_BodilyNEC.[Year 5], [Year
5]*[AveRestCoeff]*[EstimatedDaysAway]*[WRP]*[Wage_Worker]*8 AS Year5_WRP,
Illness_BodilyNEC.[Year 4], [Year
4]*[AveRestCoeff]*[EstimatedDaysAway]*[WRP]*[Wage_Worker]*8 AS Year4_WRP,
Illness_BodilyNEC.[Year 3], [Year
3]*[AveRestCoeff]*[EstimatedDaysAway]*[WRP]*[Wage_Worker]*8 AS Year3_WRP,
Illness_BodilyNEC.[Year 2], [Year
2]*[AveRestCoeff]*[EstimatedDaysAway]*[WRP]*[Wage_Worker]*8 AS Year2_WRP,
Illness_BodilyNEC.[Year 1], [Year
1]*[AveRestCoeff]*[EstimatedDaysAway]*[WRP]*[Wage_Worker]*8 AS Year1_WRP
```

```
FROM ((CompanyInput INNER JOIN (SIC_Wage INNER JOIN Illness_BodilyNEC ON
SIC_Wage.SIC_Code = Illness_BodilyNEC.SIC_Code) ON CompanyInput.SIC_Code =
Illness_BodilyNEC.SIC_Code) INNER JOIN AveRestCoeff ON
Illness_BodilyNEC.SIC_Code = AveRestCoeff.SIC_Code) INNER JOIN
DaysAwayExposure ON Illness_BodilyNEC.Exposure_Code =
DaysAwayExposure.Exposure_Code;
```

D.3.2 Selected SQL Query Code for Investment Estimate

// Estimate investment needed for basic ergonomics program

```
SELECT SIC_Wage.SIC_Code, SIC_Wage.SIC_Descript, P_BasicProgram.P_Code,
SIC_Wage.Wage_Managerial, P_BasicProgram.M_Time,
P_BasicProgram.TimePerEmp, CompanyInput.N_Worker,
[Wage_Managerial]*[M_Time]+[TimePerEmp]*[N_Worker]*[Wage_Managerial] AS
Cost
FROM P_BasicProgram, SIC_Wage INNER JOIN CompanyInput ON
SIC_Wage.SIC_Code = CompanyInput.SIC_Code;
```

// Estimate investment needed for ergonomics control based on occupation type and scenario related to occupation code

```
SELECT CompanyInput.OCC_Code, Occupation.Occ_Descript,
OCCGroup_OCCode.OCC_Group, OccupationGroup.OCC_Group_Descript,
OCCGroup_SCode.S_Code, P_ErgoIntervention.S_Description,
P_ErgoControl.ControlDescript, CompanyInput.N_Wst,
Update_MSDCases.Year1_MSD, P_ErgoControl.EmpPerControl,
P_ErgoControl.ControlCost,
(([Year1_MSD]/[EmpPerControl])*[ControlCost])*(10/[ControlLife]) AS TotalCost,
P_ErgoControl.ControlLife, P_ErgoControl.TrainingCost
FROM (P_ErgoIntervention INNER JOIN ((OccupationGroup INNER JOIN
(((Occupation INNER JOIN OCCGroup_OCCode ON Occupation.OCC_Code =
OCCGroup_OCCode.OCC_Code) INNER JOIN CompanyInput ON
Occupation.OCC_Code = CompanyInput.OCC_Code) INNER JOIN Update_MSDCases
ON CompanyInput.SIC_Code = Update_MSDCases.SIC_Code) ON
OccupationGroup.OCC_Group = OCCGroup_OCCode.OCC_Group) INNER JOIN
OCCGroup_SCode ON OccupationGroup.OCC_Group =
OCCGroup_SCode.OCC_Group) ON P_ErgoIntervention.S_Code =
OCCGroup_SCode.S_Code) INNER JOIN P_ErgoControl ON
P_ErgoIntervention.S_Code = P_ErgoControl.S_Code;
```

// Estimate investment needed for ergonomics task analysis

```
SELECT CompanyInput.SIC_Code, SIC_Wage.SIC_Descript,
P_FullProgram_JobAnalysis.P_Code, SIC_Wage.Wage_Worker,
SIC_Wage.Wage_Managerial, P_FullProgram_JobAnalysis.M_TimePerMSD,
```

```
P_FullProgram_JobAnalysis.W_TimePerMSD, Update_MSDCases.Year1_MSD,
Update_MSDCases.Year2_MSD,
([Year1_MSD]+[Year2_MSD])*([Wage_Worker]*[W_TimePerMSD]+[Wage_Manageri
al]*[M_TimePerMSD]) AS Cost
FROM P_FullProgram_JobAnalysis, (SIC_Wage INNER JOIN CompanyInput ON
SIC_Wage.SIC_Code = CompanyInput.SIC_Code) INNER JOIN Update_MSDCases
ON SIC_Wage.SIC_Code = Update_MSDCases.SIC_Code;
```

// Estimate investment needed for MSD management

```
SELECT CompanyInput.SIC_Code, SIC_Wage.SIC_Descript,
P_FullProgram_MSDMngt.P_Code, SIC_Wage.Wage_Worker,
SIC_Wage.Wage_Managerial, P_FullProgram_MSDMngt.M_Time,
Update_MSDCases.Year1_MSD, [M_Time]*[Wage_Managerial]*[Year1_MSD] AS
Cost
FROM P_FullProgram_MSDMngt, (SIC_Wage INNER JOIN CompanyInput ON
SIC_Wage.SIC_Code = CompanyInput.SIC_Code) INNER JOIN Update_MSDCases
ON SIC_Wage.SIC_Code = Update_MSDCases.SIC_Code;
```

// Estimate investment needed for ergonomics control and program evaluation elements

```
SELECT CompanyInput.SIC_Code, SIC_Wage.SIC_Descript,
P_FullProgram_ProgEvaluation.P_Code, SIC_Wage.Wage_Managerial,
P_FullProgram_ProgEvaluation.M_Time, [M_time]*[Wage_Managerial] AS Cost
FROM P_FullProgram_ProgEvaluation, SIC_Wage INNER JOIN CompanyInput ON
SIC_Wage.SIC_Code = CompanyInput.SIC_Code;
```

// Estimate investment needed fortraining of employees

```
SELECT CompanyInput.SIC_Code, SIC_Wage.SIC_Descript,
P_FullProgram_Training.P_Code, CompanyInput.N_Worker, SIC_Wage.Wage_Worker,
SIC_Wage.Wage_Managerial, P_FullProgram_Training.M_Time,
P_FullProgram_Training.W_Time,
IIf([P_Code]="FP02",[N_Worker]*[Wage_Worker]*[W_Time],0)+IIf([P_Code]="FP01"
,[Wage_Managerial]*[M_Time],0)+IIf([P_Code]="FP03",[Wage_Managerial]*[M_Time
]*[N_Worker]/20,0) AS Cost
FROM P_FullProgram_Training, SIC_Wage INNER JOIN CompanyInput ON
SIC_Wage.SIC_Code = CompanyInput.SIC_Code
ORDER BY P_FullProgram_Training.P_Code;
```

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