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Estimating investment worthiness of an ergonomic intervention for preventing low back pain from a firm's perspective

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Abstract

A mathematical model was developed for estimating the net present value (NPV) of the cash flow resulting from an investment in an intervention to prevent occupational low back pain (LBP). It combines biomechanics, epidemiology, and finance to give an integrated tool for a firm to use to estimate the investment worthiness of an intervention based on a biomechanical analysis of working postures and hand loads. The model can be used by an ergonomist to estimate the investment worthiness of a proposed intervention. The analysis would begin with a biomechanical evaluation of the current job design and post-intervention job. Economic factors such as hourly labor cost, overhead, workers' compensation costs of LBP claims, and discount rate are combined with the biomechanical analysis to estimate the investment worthiness of the proposed intervention. While this model is limited to low back pain, the simulation framework could be applied to other musculoskeletal disorders. The model uses Monte Carlo simulation to compute the statistical distribution of NPV, and it uses a discrete event simulation paradigm based on four states: (1) working and no history of lost time due to LBP, (2) working and history of lost time due to LBP, (3) lost time due to LBP, and (4) leave job. Probabilities of transitions are based on an extensive review of the epidemiologic review of the low back pain literature. An example is presented.

Keywords

spine; cost-benefit; investment; intervention

1. INTRODUCTION

Low back pain is the most common reason for days away from work, according to Bureau of Labor Statistics Data (Courtney and Webster, 1999). Data from Washington State's Department of Labor and Industries, which is the workers' compensation state fund insurer for Washington State, indicates that non-traumatic soft-tissue musculoskeletal disorders of the back accounted

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for 14.4% of all claims between 1992 and 2000 (MacDonald *et al.*, 1997). These claims accounted for \$1.5 billion in direct costs, and the average cost was \$7,541. For a diagnosis of sciatica, which is caused by lumbar disc herniation, the average cost was \$51,269 for medical aid and lost wages. Occupational low back pain represents a significant public health problem and economic burden to employers.

Maximizing profit is a powerful motivation for firms to invest in ergonomic interventions to prevent work-related musculoskeletal disorders, although it is not the sole motivation. In order to maximize profit, a firm must allocate financial capital to projects that meet investment criteria set by corporate financial officers. Thus, a project must meet an internal rate of return “hurdle rate” or produce a positive net present value (NPV) (Park, 2002). The NPV summarizes the projected flow of economic benefits and costs in terms of current dollars, and it is a very common method for evaluating capital projects in corporate finance and engineering economy (Park, 2002). A positive NPV indicates the proposed intervention should provide a favorable return on investment; a negative NPV suggests the project is not economically worthwhile from the perspective of the firm.

While there is much discussion about the need to cost-justify ergonomics (Painter and Smith, 1986; Hendrick, 1996; Beevis, 2003; Beevis and Slade, 2003; Hendrick, 2003; MacLeod, 2003) and retrospective cost-benefit evaluations of interventions (Seeley and Marklin, 2003; Sen and Yeow, 2003), few actual tools are available for the ergonomics practitioner for prospective evaluation of investment worthiness. Moreover, the tools that do exist do not directly link changes in biomechanical exposure to the NPV of expected cost savings.

The objective of this project was to develop a model for estimating the net present value of costs and cost-savings resulting from an investment in an ergonomic intervention that reduces biomechanical stress on the low back. The model can assist occupational ergonomists in justifying ergonomic interventions to management; it will be made available to the ergonomics community as part of the Three-Dimensional Static Strength Prediction Program developed and distributed by the University of Michigan's Center for Ergonomics.

2. MATERIALS AND METHODS

2.1 Model overview

The model integrates biomechanics, epidemiology, and finance to produce a statistical distribution of the NPV of the cash flows corresponding to the costs and benefits of the intervention (figure 1). The model is based on static two-dimensional biomechanical analyses of the pre- and post-intervention jobs. The resulting predictions of L5/S1 spinal compression force are combined with epidemiological data on LBP risk to estimate changes in LBP injury rates. These changes are combined with workers' compensation data to compute the change in workers' compensation-related cost, replacement labor cost, and productivity increase to be used as an estimate of the annual cash flow accruing due to the intervention. Then the NPV of the cash flow, including the cost of the intervention and its salvage value at the end of its life, is discounted at rate, r , to produce the NPV. Since some of the factors that affect workers' compensation costs are highly variable, such as time off work, the model is stochastic. The injury cost model is implemented as a discrete event simulation using Monte Carlo simulation methods. The output of the model is a relative frequency distribution of NPV, mean value of NPV, 5th and 95th percentiles of the NPV distribution, and the probability that NPV is positive. The analyst must choose the discount rate (usually set by corporate policy), planning horizon, and costs.

2.2 Biomechanical model

Pre- and post-intervention L5/S1 spinal compression forces are estimated using the static two-dimensional biomechanical model of the low back developed by Chaffin (1969) and fully described in Chaffin and Andersson (1984). Thus, inputs to the model consists of the body posture, externally applied hand force, and angle of application of the hand force.

2.3 Injury rate computation

The exposure-response relationship for LBP links biomechanical exposure to injury and lost-time costs. We selected L5/S1 compression force as the exposure measure based on a systematic review of 7,470 published papers on occupational low back pain (Nelson and Hughes, 2007). The criteria used to select papers for the systematic review were that direct observation or videotaping of study participants (or a sample thereof) must have been carried out, and that standard biomechanical methods, indices, or models must have been used to quantify postures, spinal compression, or lifting weight/frequency/duration (vibration as a risk factor was not considered). The study must have expressed back outcomes as workers' compensation claims, sickness/accident claims, OSHA log or other company-specific incident reports. Additional criteria included that the paper must have studied an occupational group in its usual work environment and the study must have been conducted in an industrial, health care, construction or other work environment with potential for heavy exposure to physical back stressors. Office environment studies were excluded. A total of 18 publications describing 15 research studies were identified that met these criteria, and a study conducted by Chaffin and Park (1973) was selected as the most useful for integrating with a biomechanical job analysis model. While that study expressed exposure in terms of lifting strength ratio, Chaffin re-calculated the LBP injury incidence as a function of L5/S1 compression force using his two-dimensional static strength prediction model (Chaffin, 1969; Chaffin and Andersson, 1984) for inclusion in a National Institute for Occupational Safety and Health (NIOSH) report (NIOSH, 1981). Our model uses the data reported in the NIOSH guide to LBP incidence from L5/S1 compression:

$$I(E) = \begin{cases} 2.2 & \text{if } E \leq 2450 \text{ N L5/S1 compression} \\ 8.8 & \text{if } 2450 < E \leq 4410 \text{ N L5/S1 compression} \\ 9.7 & \text{if } 4410 < E \leq 6370 \text{ N L5/S1 compression} \\ 18.8 & \text{if } E > 6370 \text{ N L5/S1 compression} \end{cases}$$

where incidence is expressed per 200,000 person-hours.

2.4 Injury cost model

The primary focus of the injury cost model is estimating the time-loss and workers' compensation costs from workplace measurements, B_t^{injury} . The model was based on a four-state representation of a worker's low back pain status (figure 2): (1) working and no history of lost time due to LBP, (2) working and history of lost time due to LBP, (3) lost time due to LBP, and (4) leave job. Definitions for these states include whether or not there has been a previous episode of lost time due to LBP due to the extensive literature showing that history of LBP is a powerful predictor of future LBP occurrence. Figure 2 presents the allowable transitions by arrows.

The injury cost model is a stochastic simulation, and it works by simulating the life of each worker individually. For example, the person starts in state 1, which means she/he is working and does not have a history of back pain. The computer determines the amount of time the person continues to work pain-free. That is, every day of the simulated time the computer draws

a random number to determine whether the worker gets injured, quits, or continues to work pain-free. If the random number is such that the worker leaves work due to a back injury (moves to state 3), then the computer determines how long the worker will remain off work by randomly choosing the number of days to remain in state 3. This process continues until the computer reaches the end of the planning horizon. The total costs associated with being each state are computed and stored for the net present calculations, which are described in the next section.

The employee transitions between states according to probabilistic rules, and the transitions are determined daily. The transition from state 1 to state 3 is modeled each day with a probability $p^{1 \rightarrow 3}(E)$, where E is the biomechanical exposure (L5/S1 compression force). Similarly, the daily probability of going from state 1 to state 4 is $p^{1 \rightarrow 4}$. The probability of remaining in state 1 is $1 - p^{1 \rightarrow 3} - p^{1 \rightarrow 4}$. The transitions from state 2 are modeled similarly using probabilities $p^{2 \rightarrow 3}(E)$ and $p^{2 \rightarrow 4}$. The probability of going from state 3 to state 4 is $p^{3 \rightarrow 4}$ and is invariant of time. Once in state 4, the person remains in state 4. A Weibull distribution is used to model the transition from state 3 to state 2, $p^{3 \rightarrow 2}$. While we selected Weibull parameters derived from the data set of Williams *et al.* (1998) for use in our example simulation, data from other studies could reasonably be used (Infante-Rivard and Lortie, 1996; Oleinick *et al.*, 1996; Hashemi *et al.*, 1998; Williams *et al.*, 1998; Dasinger *et al.*, 1999). The Weibull distribution has the very useful quality of a long tail that represents infrequent but very costly claims, including permanent disability.

The daily probability of making a transition from state 1 to 3 (current time loss due to LBP) was computed by normalizing the exposure-dependent incidence, $I(E)$, which was reported per 200,000 person-hours (NIOSH, 1981), to an hourly value and multiplying by an eight-hour work day:

$$p^{1 \rightarrow 3}(E) = \left(\frac{I(E)}{200,000} \right) \times 8 = 0.00004 \times I(E)$$

The probability of going from state 2 to 3 is modeled as $p^{2 \rightarrow 3} = 2.2 p^{1 \rightarrow 3}$ (the value of 2.2 is the median of estimates reported in the epidemiology literature (Venning *et al.*, 1987; Riihimaki *et al.*, 1989; Ryden *et al.*, 1989; Heliovaara *et al.*, 1991; Zwerling *et al.*, 1993; Fuortes *et al.*, 1994; Niedhammer *et al.*, 1994; Riihimaki *et al.*, 1994; Thorbjornsson *et al.*, 1998; van Poppel *et al.*, 1998; Kerr *et al.*, 2001; Hoozemans *et al.*, 2002; Elders *et al.*, 2003)).

The cost of being in each state for a day is assigned. The cost includes the average daily workers' compensation cost for a LBP claim and the daily cost of replacement labor. The model computes b_d^{injury} , which is the daily cost directly related to the injury (workers' compensation) occurring on day d . Therefore, the daily simulation data, b_t^{injury} , for year t is aggregated into $B_t^{raw injury}$ using

$$B_t^{raw injury} = \sum_{d=365 \times (t-1)+1}^{365 \times t} b_d^{injury}$$

Workers' compensation-related costs, B_t^{injury} , are not necessarily equal to $B_t^{raw injury}$ because an individual employer may not bear the full cost at the time of the injury and it may pay that cost through increased experience rating factors years after the injury. While a self-insured company will pay the full cost of this loss in the year it occurs, smaller firms may be part of a larger risk pool and they may actually pay the cost in later years due to a modification of their experience rating. Thus, we introduce two parameters, t_{delay} , and β . t_{delay} is the time it takes for the

experience rating to be adjusted to reflect the losses incurred in year t . β is the fraction of the actual cost the employer ends up paying (it is not always 1 because of risk pool sharing of costs). Then, the general form of the annual injury-related cost to the firm is

$$B_t^{injury} = \beta \times B_{t-t_{delay}}^{raw\ injury}$$

The cost of replacement labor depends on the amount of lost time due to injury. The injury cost model also computes $b_d^{replacement\ labor}$, which is the cost of replacement labor on day d , based on how many days are spent in the lost-time state. The cost savings of replacement labor is computed on an eight-hour basis per day at a pay rate that depends on how the employer typically addresses lost labor. If the employer chooses to make up labor losses by paying overtime, then the cost must include the 50% wage premium the employer pays for overtime. Other options include hiring temporary workers, and this has its own costs associated with recruitment and training. Daily costs are aggregated into annual costs using

$$B_t^{replacement\ labor} = \sum_{d=365 \times (t-1) + 1}^{365 \times t} b_d^{replacement\ labor}$$

2.5 Investment worthiness model from a firm's perspective

The model is based on computing the net present value of after-tax cash-flow resulting from the intervention:

$$NPV = \sum_{t=0}^H \frac{1}{(1+r)^t} A_t$$

where A_t is the after-tax cash flow for year t , r is the discount rate, and H is the planning horizon in years. In order to compute A_t , we must determine the after-tax benefit. To do this, we must estimate before-tax cash flow:

$$F_t = B_t^{injury} + B_t^{replacement\ labor} + B_t^{production\ \&\ quality}$$

Changes in production and quality, $B_t^{production\ \&\ quality}$, can be significant. However, the model formulation does not allow for $B_t^{production\ \&\ quality}$ to depend on whether an employee has low back pain or not; $B_t^{production\ \&\ quality}$ should be estimated based on the aggregate change in production and quality resulting from the intervention. Taxes in year t must be computed using

$$T_t = \alpha \times (B_t^{injury} + B_t^{replacement\ labor} + B_t^{production\ \&\ quality} + D_t - C_t)$$

where D_t the depreciation in year t and α is the marginal tax rate experienced by the firm. Four types of depreciation are implemented in the model for the user to choose from: (1) straight-line, (2) sum-of-years digits, (3) declining balance, and (4) accelerated cost recovery. The depreciation schedule, which is computed using standard accounting methods (Park, 2002), determines D_t . To compute the after-tax cash flow, we must account for taxes (T_t), initial cost of intervention (C_0), annual cost of the intervention (C_t), and the salvage value S :

$$A_t = \begin{cases} -C_0 & \text{if } t=0 \\ F_t - T_t - C_t & \text{if } t=1, \dots, T-1 \\ F_t - T_t - C_t + S & \text{if } t=T \end{cases}$$

These are estimated using traditional industrial engineering estimation methods. In addition to the initial purchase cost in year $t=0$, the annual cost includes maintenance and service agreement costs.

2.6 Model parameters

Cost of injury claims and replacement labor should come from the firm's records or its workers' compensation carrier. The planning horizon, discount rate, tax rate, and depreciation schedule are determined by the corporate financial department of the firm. Intervention costs and salvage value are determined by market prices. Parameters for the biomechanical model (segment masses, link length, centers of mass, etc.) were taken from Chaffin and Andersson (1984). The moment arm of the erector spinae muscle group was assumed to be 5.0 cm. Table 1 provides a description of the non-biomechanical parameters in the model; the biomechanical parameters (anthropometry, segmental mass locations, etc.) are described fully in Chaffin and Andersson (1984).

2.7 Model implementation

The simulation consists of computing the NPV of the projected cash flow over the H -year horizon for each of N hypothetical employees. For each person, a stochastic simulation is conducted to generate a state transition history for each of two conditions: (1) no intervention, and (2) with intervention. NPV is computed for that person and stored. The process is repeated N times. Summary statistics and the relative frequency distribution are computed at the end.

2.8 Example

To illustrate the use of this model, consider a hypothetical example of modifying a job consisting of lifting 10 kg parts from a pallet to a conveyor line at a factory. The job requires the employee to lift the part from a low level far from the body, as there is no room to walk around the pallet to get closer to the part. The intervention is a lift table with a rotating platform that allows the part to be presented to the employee at waist height without a long reach. Table 1 presents the parameters used for the analysis. Workers' compensation costs were taken from data published by Washington State Department of Labor and Industries (Silverstein and Kalat, 2002) (average daily cost of a claim, which is \$70.48, was computed as the ratio of average LBP claim cost to average time-loss days). We assume the firm is self-insured, so $\beta = 1$ and $t_{\text{delay}} = 0$. The simulation was run for $N=1,000$ hypothetical employees. Sensitivity analyses were also performed to assess the importance of the discount rate and transition probabilities. Each simulation run was performed using 1000 hypothetical employees, and 10 simulation runs were performed for each set of model parameters analyzed in the sensitivity analysis. Sensitivity analyses were performed for the length of the planning horizon, discount rate, injury probability (transition from state 1 to 2), and the number of days of work (transition from state 2 to 3). The analysis of lost time was done by simply reducing the number of days in state 2 by a fixed amount.

RESULTS

The median NPV of the cash flow resulting from the intervention in the example was \$3,598, which means that there was a 50% chance that the NPV will be greater than this value. The average NPV was \$4,851. The 5th and 95th-percentiles of the distribution were \$-24,574 and

\$37,201, respectively. Figure 3 shows the relative frequency plot of NPV when a discount rate of 7% is used. In fact, 61% of the simulation runs produced a positive NPV; therefore, it is more likely than not that this investment would meet the investment criteria of having a positive NPV when a rate of return of 7% was used in the analysis. The wide confidence interval means that the actual NPV could vary widely depending on the specific injury experience with that job.

Sensitivity analyses showed that the planning horizon, discount rate, transition probabilities, and lost work days affected NPV (figure 4). A longer planning horizon provides more time for benefits of the intervention to accrue, which increases NPV. On the other hand, increasing the discount rate reduces the current value of the benefits that occur in the future, so a higher discount rate reduces NPV. The probability of going from state 1 to state 3 (i.e. becoming injured) affected NPV, as expected. This clearly points to the importance of reducing injury risk through ergonomic intervention. Reducing the amount of time loss each time there is a back injury, which models effective return-to-work programs, mitigated the economic benefit of the ergonomic intervention. However, such an analysis does not account for the contribution of the ergonomic intervention to the return-to-work program.

DISCUSSION

A stochastic model based on epidemiologic data and biomechanical modeling was developed to estimate the net present value of the cash flow over a finite time horizon resulting from an investment in an ergonomic intervention to prevent lifting-related occupational low back pain. The material handling example illustrated how the model can be used to evaluate the investment worthiness of an intervention. While the model is limited to occupational low back pain, the stochastic simulation framework could be applied to other musculoskeletal disorders.

The model goes beyond existing cost-benefit methods by synthesizing biomechanics, epidemiology, and finance into one analysis tool. Other methods of cost-justification in ergonomics do not quantitatively link biomechanical job analyses to changes in injury costs. Moreover, the most detailed model yet developed by Oxenburgh (Oxenburgh, 1991; Oxenburgh *et al.*, 2004) is based on pay-back period as a metric of investment worthiness. Unfortunately for practicing ergonomists who would like to use that model, many firms use NPV or internal rate of return as methods for evaluating capital budgeting decisions and pay-back period is used less often (Graham and Harvey, 2001). Proprietary methods, such the Return on Health, Safety, and Environmental Investments (ROHSEI) software tool developed by ORC Worldwide (Washington, DC, USA), do not include a tool for linking changes in biomechanical stresses on the low back to changes in injury costs.

We chose to model NPV using Monte Carlo simulation because some of the most important cost-drivers in the model, such as lost time, are best described using probability distributions. Monte Carlo simulation is a well-accepted method in engineering economics (Park and Sharp-Bette, 1990). We chose to use NPV instead of IRR as the primary metric of investment worthiness because the IRR is not mathematically well-behaved when the cash flow changes sign over the planning horizon. Specifically, the IRR can be an irrational number when the cash flow switches from positive to negative multiple times. Using Monte Carlo simulation to model parameters as random variables creates situations where this may occur. Therefore, NPV was selected to avoid the problem of interpreting irrational rates of return.

Erector spinae moment arm is a critical parameter in low back models because it is inversely related to spinal compression. Although more recent models have used a larger moment arm, we chose to use a moment arm value that was consistent with what Chaffin used to derive the exposure-injury relationship reported in the 1981 NIOSH Work Practices Guide from his

epidemiological study (Chaffin and Park, 1973). At the time Chaffin was conducting the re-analysis of his epidemiological data for NIOSH, his research group was using an erector spinae moment arm value of 5.0 cm for all low back modeling (Chaffin, 1969; Chaffin and Andersson, 1984). While it would be possible to integrate our approach with many biomechanical models of the low back, it is important to note if the assumed erector spinae moment arm differs from this value.

The model has several limitations. It does not include the effects of low back pain for employees who do not file workers' compensation claims, which may include reduced productivity and increased sick leave. The model also limits the use of the four-state transition scheme to labor costs and does not extend it to productivity and quality, which must be modeled using

$B_t^{production\&quality}$. A departure from employment with the firm is not broken down into disability claim vs. non-disability claim; a retirement due to permanent LBP disability is modeled as a very prolonged stay in state 3. This infrequent but very costly event is included in the model by the long tail of the Weibull distribution.

The range of applications for the model is also limited by the study population studied by Chaffin and Park (1973), which was a manufacturing workforce. Thus, the model is not suitable for studying seating and light work in the office environment. However, the jobs studied by Chaffin and Park (1973) had heavy biomechanical exposures, which suggests that their results should apply to jobs with similar heavy exposures. For example, other occupations with heavy exposures include manufacturing, health care, and construction.

We chose to model the investment worthiness of interventions to prevent occupational LBP because LBP is a significant public health problem and cost driver for firms. It is important to recognize, however, that firms invest in ergonomics for many reasons beyond project return-on-investment, including the ethical obligation of providing a safe workplace, regulatory compliance, remaining competitive in the market for talented employees, and collective bargaining. Demonstrating a positive NPV should be viewed as one component of making a successful business case for an ergonomics intervention.

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Figure 1.

Model schematic. Analyses are performed for the pre-intervention and post-intervention conditions to estimate pre- and post-injury rates. The injury rates are fed into a stochastic simulation model, which is represented in the dotted-line box. Estimation of injury rates has three components: (1) specifying work posture and load for the most biomechanically stressful part of the job, (2) using a two-dimensional biomechanical model to predict L5/S1 compression force, (3) using an exposure-response relationship to estimate LBP injury rate from L5/S1 compression. The stochastic model uses a discrete event simulation approach to simulate the progression of a worker through the four-state health state model presented in figure 2. Financial modeling parameters, which include intervention cost, discount rate, and planning

horizon, are added to this simulation to compute NPV of costs and cost savings in the investment worthiness model. This simulation is performed N times and stored. The result of the N simulations is the final output of the model. Grey boxes represent computational steps; white boxes with solid borders represent data or results of computations.

Figure 2.

The model uses Monte Carlo simulation to compute the statistical distribution of NPV, and it uses a discrete event simulation paradigm in which transitions between four health states are possible: (1) working and no history of lost time due to LBP, (2) working and history of lost time due to LBP, (3) lost time due to LBP, and (4) leave job. Probabilities of transitions are based on an extensive review of the epidemiologic review of the low back pain literature.

Figure 3. Relative frequency histogram of net present value (NPV) for example. Although it spans zero (95% C.I. is $[-24,574, 37,201]$), the mean is \$4,851. A discount rate of 7% was used in the simulation.

Figure 4.

Sensitivity analysis for planning horizon (A), discount rate (B), increase in injury probability (from state 1 to state 3) (C), and decreasing time loss for each back injury episode (D). Box-and-whisker plots show the range produced for each set of 10 simulations performed for one combination of model parameters.

Table 1

Model parameters

Parameter	Notation	Value used in example simulation
Biomechanical exposure (L5/S1 compression force in N) [#] , which is computed from a static 3D biomechanical model (Chaffin and Andersson, 1984)	E	6794 N (pre-intervention) 6794 N (post-intervention)
Injury rate	$I(E)$	*
Daily probability of making transition from state 1 to state 3	$p^{1 \rightarrow 3}(E)$	*
Daily probability of making transition from state 1 to state 4	$p^{1 \rightarrow 4}$	0.0000001
Daily probability of making transition from state 2 to state 3	$p^{2 \rightarrow 3}$	*
Daily probability of making transition from state 2 to state 4	$p^{2 \rightarrow 4}$	0.0000001
Daily probability of making transition from state 3 to state 4	$p^{3 \rightarrow 4}$	0.0000001
Daily probability of making transition from state 3 to state 2	$p^{3 \rightarrow 2}$	*
Daily cost directly related to injury on day d	b_d^{injury}	\$70.48
Delay between injury and change in workers' compensation premium	t_{delay}	0
Fraction of actual cost paid by employer	β	1
Change in cost directly related to injury that is paid by employer in year t	$B_t^{raw injury}$	*
Daily cost directly related to injury that is paid by employer through workers' compensation in year t	B_t^{injury}	*
Change in cost directly related to injury in year t	B_t^{injury}	*
Change in daily cost of replacement labor on day d	$b_d^{replacement labor}$	\$120/day
Change in cost of replacement labor in year t	$B_t^{replacement labor}$	*
Change in production and quality in year t	$B_t^{production \& quality}$	0
Before-tax savings for year t	F_t	*
Weibull scale parameter for lost time		0.047
Weibull shape parameter for lost time		0.737
Discount rate	r	7%
After-tax savings for year t	A_t	*
Marginal tax rate	a	35%
Depreciation in year t	D_t	^
Taxes on the change in cost in year t	T_t	*
Initial cost of ergonomic intervention in year 0	C_0	\$3,000
Annual cost of intervention (maintenance etc.) in year t	C_t	\$100
Planning horizon in years	H	10 years
Salvage value at end of planning horizon	S	\$200

[#] L5/S1 spinal compression force is computed using a standard static 2D biomechanical model of lifting, and the biomechanical parameters are well-described in Chaffin and Andersson (1984).

[^] Depreciation is dictated by accounting standards, and this simulation used the straight-line method for computing the amount in each year (Park, 2002).

* This parameter is computed from other parameters using the methods described in the text.