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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.

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 for 14.4% of all claims between 1992 and 2000 (Silverstein and Kalat, 2002). These claims accounted for $1.5 billion in direct costs and the average cost was $7541. 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 (IRR) "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 that 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

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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 (Fig. 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 consist 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 7820 published papers on occupational low back pain (Nelson and Hughes, in press). 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, Occupational Safety and Health Administration 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:

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

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 change in 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 (Fig. 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. Fig. 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 $p^{1\to3}(E)$, where E is the biomechanical exposure (L5/S1 compression force). Similarly, the daily probability of going from state 1 to state 4 is $p^{1\to4}$. The probability of remaining in state 1 is $1 - p^{1\to3} - p^{1\to4}$. The transitions from state 2 are modeled similarly using probabilities $p^{2\to3}(E)$ and $p^{2\to4}$. The probability of going from state 3 to state 4 is $p^{3\to4}$ 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, $p^{3\to2}$. 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