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Net-cost model for workplace interventions

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Abstract

Problem: Few methods exist for comprehensively examining the costs and benefits of ergonomic interventions applicable to a variety of economic sectors and settings. *Methods:* An instrument for data collection and data analysis at the facility level is presented. In this net-cost model intervention costs are defined by equipment and labor costs for the interventions as well as the avoided costs of lost work time, medical care, and productivity improvements. *Results:* Net-cost estimates for three case studies show that ergonomic interventions applied appropriately can result in substantial cost savings for the companies. *Discussion:* It would be prudent to incorporate a protocol for collecting cost and effectiveness data in the standard operating procedures of companies introducing ergonomic interventions. Validation of the net-cost model through prospective studies is necessary. *Impact on industry:* This model may be used to determine the net-cost of implemented or proposed ergonomic interventions in industrial facilities.

Keywords: Low back pain; Ergonomic interventions; Net-cost model; Economic evaluation of occupational interventions; Net-cost questionnaire

1. Introduction

This paper presents a model approach at a micro (company) level for the economic evaluation of interventions to reduce work-related low back pain (LBP). The study provides a simple transparent framework to estimate the net economic costs of investments in ergonomic interventions at the company level to reduce occupational morbidity.

The net-cost model, which is an instrument for data collection and data analysis at the facility level, was developed. All costs are annualized costs and are calculated at the level of an individual organization. Costs of low back pain interventions are defined comprehensively by incorporating not only the costs of investment of equipment and labor for the interventions, but also by taking into account the avoided costs of lost work time, medical care costs, and productivity improvements.

The net-cost model has been tested with the data provided by three companies in the manufacturing sector in the United States. These three case studies are presented in this article. All costs were converted to annualized cost flows at the level of an individual organization. Company A is a small wood-processing manufacturing plant owned by a multi-national corporation, with ergonomic interventions implemented for laborers and assemblers. Company B, a large multinational automotive supplier, implemented interventions for low-back pain in office workers. Company C is a major manufacturer of truck and automotive bodies and engines. Interventions were implemented for assemblers in several different lines.

2. Methods

Recent analyses of procedures for evaluating interventions for occupational safety and health of workers (Mossink, 2002; Dorman, 2000; Barefoot Economics, 2002; Department of Defense, 2002; Oxenburgh, 1994, 1997; Reville, Bhattacharya, & SagerWeinstein, 2001)

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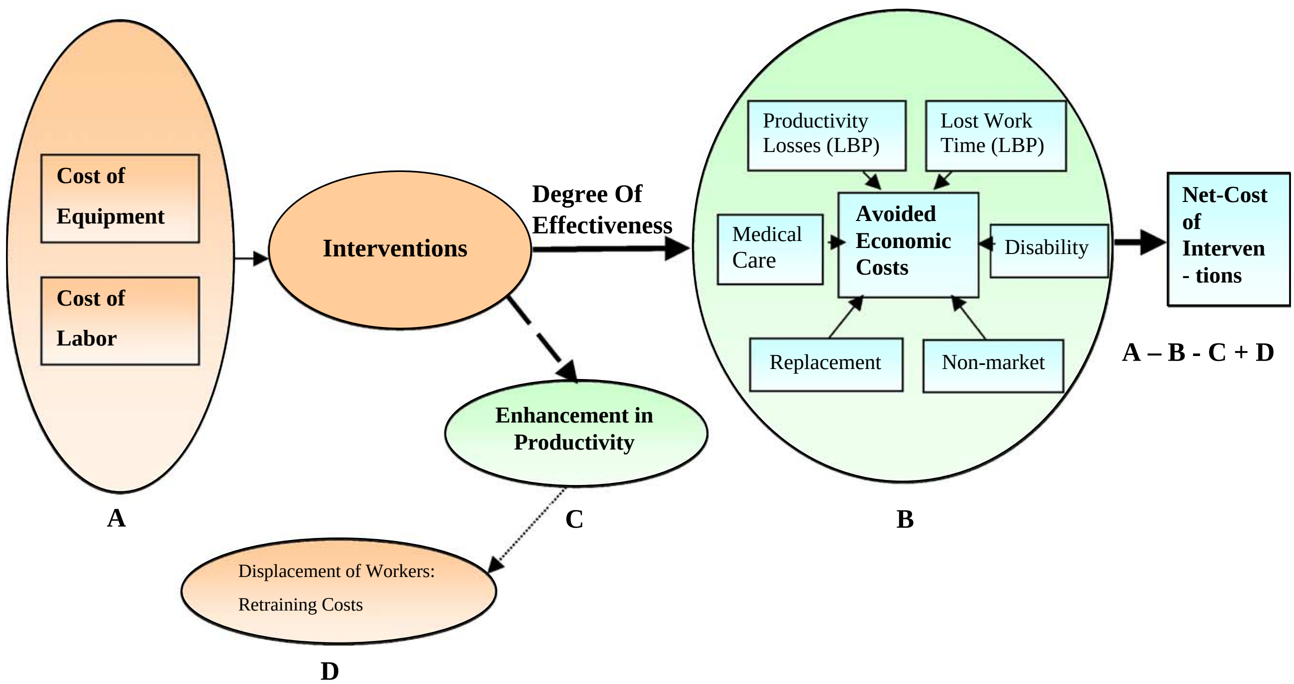

Fig. 1. A Model Overview: Annualized Net-Cost of Interventions for Preventing Occupational LBP.

have identified the different factors that play a crucial role in determining the costs of these interventions. The identified costs can be classified from the perspective of the company, worker, economy, and society as a whole.

These cost categories are not mutually exclusive and there may be a substantial overlap. For example, the cost to the company and worker would both be included as costs to the economy. However, certain costs, for example the cost of worker displacement due to the introduction of interventions that cause enhancement in productivity (especially relevant for developing economies) and might lead to unemployment would be included as costs for the economy, but not for the particular company or the injured worker. Again, certain unmeasured costs that are imposed on families of injured workers (e.g., role reversal among spouses) may not enter the market directly. These non-market costs may be ignored as costs at the economy-wide level, nonetheless they may be highly significant as components of societal cost (Levenstein, 1999).[1]

An overview of a comprehensive model is shown in Fig. 1 as a flow diagram. There are four essential components in this framework: (a) the cost of equipment and labor of the intervention enters the cost equation as a positive component; (b) the degree of effectiveness of the interventions essentially determines the value of the avoidable costs of injuries and illnesses; (c) the increase in productivity results principally from the technological design of the equipment and; (d) the displacement of workers that might result from an increase in productivity of the intervention. While both the second and third components enter the accounting equation as negative expressions and help to reduce the real cost of the intervention, the cost of retraining for displaced workers enters the equation as a positive cost from the societal point of view.

Our goal in this study, however, was to develop a standardized tool for economic analysis that would measure the net costs of interventions for the primary prevention of low back pain, primarily from the company's point of view. Due to a paucity of data, we have implemented a simple version of the net-cost model that can be implemented with the data that the participating companies and insurance companies can provide.

2.1. Model equations

The model used in our case studies to estimate the net-costs of interventions has been adapted for companies that had implemented ergonomic interventions and had made the data available to us. The equations of the model are based on the information provided by a number of studies (Dorman, 2000; Barefoot Economics, 2002; Department of Defense, 2002; Oxenburgh, 1994, 1997; Mossink, 2002). The model essentially is an accounting framework for net costs where net cost is equal to investment cost on intervention equipment plus labor costs involved in implementing the intervention

[1] Hence, this model ignores the unmeasured societal costs that are imposed upon families but do not show up as "economic costs" that enter the market directly.

(1) Annualized Net Economic Costs Of Safety Interventions For Preventing Occupational Low Back Pain (LBP) = Annualized Additional Direct Investment Costs On Equipment For Interventions + Annual Labor Costs For Implementing The Intervention - Avoided Annual Economic Costs Of LBP - Annual Value Of Increase In Productivity For All Workers Subjected To The Intervention

(2) Avoided Annual Economic Costs Of LBP = Avoided Medical Care Costs + Avoided Reduction In The Value Of Lost Work Time Due To LBP Sick Leave + Avoided Reduction In Productivity Losses Due To LBP When Not On Sick Leave

(3) Annualized Net Economic Costs Of Safety Interventions For Preventing Occupational LBP Per Worker = Annualized Net Economic Costs Of Safety Interventions /(Total Workforce In The Organization)

Direct Costs on Equipment

(4) Total Additional Direct Investment Cost Of Each Equipment = Total Direct Current Cost Of Investments In Each New Equipment After Intervention - Total Direct Costs Of Investments In Each Similar Type Of Equipment Prior To Intervention[6]

(5) Total Direct Current Costs Of Investments In Each New Equipment = Price Of Each New Equipment In 2002 Dollars * Quantity Of Each New Equipment[7]

(6) Total Direct Prior Costs Of Investments In Each Similar Type Of Equipment = Price Of Each Prior Equipment In 2002 Dollars * Quantity Of Each Equipment Prior To Intervention

(7) Capital Recovery Factor For Each Equipment = Market Rate Of Interest + Rate Of Depreciation For Each Equipment[8]

(8) Annualized Additional Direct Investment Cost Of Each Equipment = Capital Recovery Factor Of Each Equipment * Total Additional Direct Investment Cost Of Each Equipment

(9) Total Annualized Additional Direct Investment Cost Of All Equipment = Sum Of Annualized Additional Direct Investment Cost Of All Equipments Used the Interventions

(10) Annualized Additional Direct Costs Of Interventions = Total Annualized Additional Direct Investment Cost Of All Equipment + Annual Labor Costs For Intervention Implementation[9]

[6] For example, we should take the price of an ergonomically approved adjustable chair and deduct from that the price of a traditional chair that was used originally. It is this additional cost of an adjustable chair that should be treated as equipment cost.

[7] Direct costs should also include costs of operation and maintenance. We however, did not mention them in these equations because they were reported as negligible in all three case studies. Our questionnaire items presented in the appendix include them.

[8] The depreciation for each type of equipment has been calculated by taking into account the life of the equipment and their salvage value by using the depreciation formula explained in the text.

[9] For example this cost included all costs involved in training workers to use ergonomically designed equipments.

Fig. 2. Model equations.

minus avoidable health care costs of illness and injury, productivity losses due to loss in efficiency and absenteeism, and other benefits related to productivity enhancement of all workers subjected to the intervention.[2] All costs are annualized costs and are calculated at the level of an individual organization. Given the investment and labor costs of the intervention, an important factor that essentially drives the model is the degree of effectiveness of the interventions in reducing back pain. The higher the degree of effectiveness of the interventions, the higher the avoidable costs and the lower the net costs of implementing the interventions. The other major factor that influences net costs is the gain in the coefficient of productivity resulting from the ergonomic interventions. The model equations are specified in Fig. 2.

[2] Replacement costs and disability costs are not included in our equations used in the three case studies as they were not reported as relevant factors by the companies.

2.2. Data collection

A questionnaire targeted to solicit information that a company would be able to provide was developed based on the net-cost model and is presented in Table A1 in the

Avoided Medical Care Costs

(11) Total Annual Avoided Medical Care Costs = [Medical Care Costs Before Intervention (Acute Cases) - Medical Care Costs After Intervention (Acute Cases)] + [Medical Care Costs Before Intervention (Chronic Cases) - Medical Care Costs After Intervention (Chronic Cases)]

(12) Medical Care Costs Before Intervention (Acute) = Average Medical Care Cost Per Acute Case In 2002 Dollars * Number Of Employees Suffering From Acute LBP Before Intervention

(13) Medical Care Costs Before Intervention (Chronic) = Average Medical Care Cost Per Chronic Case In 2002 Dollars * Number Of Employees Suffering From Chronic LBP Before Intervention

(14) Medical Care Costs After Intervention (Acute) = Medical Care Cost Per Case In 2002 Dollars * Number Of Employees Suffering From Acute LBP After Intervention

(15) Medical Care Costs After Intervention (Chronic) = Medical Care Cost Per Case In 2002 * Number Of Employees Suffering From Chronic LBP After Intervention

Loss In Productivity Due To LBP

(16) Avoided Productivity Losses Due To LBP = Reduction In The Value Of Lost Work Time Due To LBP + Reduction In Efficiency Due To LBP When Not On Leave

(17) Reduction In The Value Of Lost Work Time Due To LBP = Value Of Lost Work Time Due To Sick Leave Before Intervention - Value Of Lost Work Time Due To Sick Leave After Intervention

(18) Value Of Lost Work Time Due To Sick Leave Before Intervention = Number Of Missed Days Of Work Before Intervention * Wage Per Hour In $ Paid During Sick Leave Due To Back Pain * Number Of Work Hours Per Day

(19) Value Of Lost Work Time Due To SickLeave After Intervention = Average Number Of Missed Days Of Work After Intervention * Wage Per Hour In $ Paid During Sick Leave Due To Back Pain * Number Of Work Hours Per Day

(20) Reduction In Efficiency Due To LBP When Not On Leave = Total Number Of Employees Suffering From LBP Without Leave * Number Of Days Of Duration Of LBP For Each Employee * Coefficient Of Loss In Productivity

(21) Coefficient Of Loss In Productivity In Dollars = Average Wage Rate – Adjusted Average Wage Rate Taking Into Account The Percentage Loss In Productivity

Enhancement In Productivity

(22) Annual Value Of Increase In Productivity Due To The Intervention = Number Of Workers Subjected To Intervention * Number Of Work Hours Per Week * Number Of Weeks Worked Per Year * Coefficient Of Productivity Gain Due To The Intervention

(23) Coefficient Of Gain In Productivity In Dollars = Adjusted Average Wage Rate Taking Into Account The Percentage Gain In Productivity - Average Wage Rate

Fig. 2 (*continued*).

appendix. It includes questions regarding the nature of the intervention(s) for low back pain, and the number of employees suffering from back pain before and after the interventions. Pre- and post-intervention data were collected on the duration of back pain and/or disability (acute: 0–12 weeks; chronic: more than 12 weeks), number of missed days of work, and average wage of employees with back pain. Information on decrease in productivity (if any) due to back pain and increase in efficiency (if any) after the intervention was solicited.

Direct costs of the interventions, including equipment costs and any additional wages (including training costs) paid to implement the intervention, were obtained. The authors were interested in the direct additional cost that was incurred due to the introduction of the intervention. Economists call this direct additional cost the marginal cost. In other words, if we are providing ergonomically approved adjustable chairs as an intervention to prevent LBP, we should take the price of an ergonomically approved adjustable chair and deduct from that the price of the original traditional chair. This additional cost of an adjustable chair should be treated as equipment cost.

The capital recovery factor was determined for all purchased intervention equipment. The **depreciation** can be calculated with the help of the following formula:

$$K = \sum d(1+i)^{a-t} + \phi$$

K = total investment; d = depreciation; i = interest rate; a = service life of the equipment in years; t = running time variable; ϕ = salvage value of the equipment.

If one calculates the annual flat rate of depreciation based on the above formula, the depreciation rate d becomes smaller for equipment that has a longer useful life or has a high salvage value.[3] The interest rate that is used to compute the capital recovery factor represents the long run opportunity cost of private capital (rate of return on private capital).

Medical care costs were determined from state-based cost tables of compensable low back pain cases (Webster & Snook, 1994) The mean cost/case was used for acute/sub-acute cases, while the median cost/case was used for calculating medical care costs for chronic low back pain cases. Comparable data were obtained from the state workers' compensation agency for the one company where insurance was administered through a state-operated fund. All costs were converted into 2002 dollars.

Companies that had implemented ergonomic interventions were found from the OSHA and Washington State "success stories" websites, from the National Safety Council, and from independent and university-based ergonomic consultants. Thirty-seven companies were contacted, and 22 were sent questionnaires. Four completed questionnaires were received. One of these companies did not have back pain cases; the company safety personnel stated that any incipient cases were perhaps prevented by ergonomic interventions.

Three companies not answering the questionnaire did not have adequate resources to fill out the questionnaire, while two companies sent descriptive information regarding ergonomic interventions and effectiveness. An additional company could not answer the questionnaire as structured since the back pain prevention intervention component could not be separated from their overall safety program.

[3] Certain companies use the accelerated depreciation principle where they attribute a large percentage of the depreciation in the initial year to take advantage of the tax code. One could perform a sensitivity analysis of the net cost model with respect to the accelerated depreciation principle to determine its impact on annualized costs.

3. Results

The net-cost model was tested on a spreadsheet using the data supplied by three companies. Questionnaire A1 presented in the appendix was filled out by the companies and sent to the authors.

3.1. Case study A

A 123-employee wood processing plant implemented ergonomic interventions for forklift, crane and machine operators, technicians, and utility/general production workers for a period of three years. A total of 115 employees were subjected to the interventions over a period of three years. After conducting ergonomic evaluations, engineering controls and workstation modifications were instituted. New equipment included adjustable chairs, conveyors, lift tables, anti-fatigue matting, grabbers, and catwalks to minimize use of ladders. These costs are itemized in Table 1 (see Appendix). Since these different types of equipment were purchased in different years, all unit prices were adjusted to 2002 prices using the Consumer Price Index (2003) as depicted in row 5 of Table 1. By deducting the costs of equipment that were purchased before the intervention, the additional costs of equipment were obtained (row 12 of Table 1). All additional costs were annualized, by taking into account the capital recovery factor. The capital recovery factor for each type of equipment was obtained by taking the sum of the depreciation rate and a uniform rate of opportunity cost of capital of 7%. The depreciation rate for each type of equipment was determined by using the formula for depreciation cited in the earlier section, which takes into account the life of the equipment and its salvage value. The varying depreciation rates are shown in row 17 of Table 1. The total additional annualized direct cost on equipment was $4,838 as is evident from row 20 in Table 1.

A physical therapist was hired to teach employees pre-shift exercises for prevention of musculoskeletal disorders. The total direct costs of intervention on equipment as well as labor were $5,338.

Employee reported symptoms identified low back pain. Before the interventions, there were six acute cases of LBP. After the interventions, no cases of LBP were reported. In other words, the effectiveness of the interventions in curing acute back pain was reported to be 100%. Hence, all of the medical care costs prior to the interventions that totaled $1,010 (in 2002 dollars) were considered as avoided medical care costs. This resulted in a net annualized cost of interventions net of medical care costs as $4,328.

The workers in this company did not report any sick days due to acute LBP. However, the company estimated a 15% loss in productivity due to LBP. We find this figure to be

Table 1
Estimation Of Annualized Net Economic Costs Of Ergonomic Interventions For Reducing Low Back Pain — Case Study A

1	2	3	4	5	6	7	8
Direct Costs Of Investments On Interventions							
1. Type Of Equipment	Adjustable Chairs	Conveyors	Lift Tables	Matting	Grabbers	Catwalks	
2. Year Purchased	2001	2001	2000	2001	2002	2003	
3. Unit Price Of Equipment Purchased After Intervention	$350.00	$10.00	$2,500	$3.50	$7.50	$5,000.00	
4. Quantity Of Current Equipment Purchased	5	250	10	200	25	1	
5. Unit Price Of Item Adjusted To 2002 (Using CPI)	$355.53	$10.16	$2,611.79	$3.56	$7.50	$4,822.98	
6. Value Of Equipment Purchased After Intervention In 2002 Prices (Row 4 * Row 5)	$1,777.67	$2,539.53	$26,117.89	$711.07	$187.50	$4,822.98	
7. Purchase Year For Prior Equipment	1999	0	0	0	0	0	
8. Unit Price Of Prior Equipment Purchased	$50.00	$0.00	$0.00	$0.00	$0.00	$0.00	
9. Quantity Of Prior Equipment Purchased	5	0	0	0	0	0	
10. Unit Price Of Prior Equipment Adjusted To 2002 (Using CPI)	$53.99						
11. Value Of Equipment Purchased Before Intervention In 2002 Prices (Row 9 * Row 10)	$269.96	$0.00	$0.00	$0.00	$0.00	$0.00	
12. Additional Direct Investment Cost In 2002 $ (Row 6 – Row 11)	$1,507.71	$2,539.53	$26,117.89	$711.07	$187.50	$4,822.98	
13. Expected Life Of Equipment (Years)	5	20	10	5	5	20	
14. Salvage Value	$350.00	$0.00	$5,223.58	$0.00	$0.00	$0.00	
15. Net Of Savage Value (Row 12 – Row 14)	$1,157.71	$2,539.53	$20,894.31	$711.07	$187.50	$4,822.98	
16. Depreciation (Using Formula)	$188.14	$57.89	$1,413.34	$115.56	$30.47	$109.95	
17. Rate Of Depreciation (Row 16 ÷ Row 15)	0.1625	0.0228	0.0676	0.1625	0.1625	0.0228	
18. Capital Recovery Factor (Interest Rate 7% + Row 17)	0.2325	0.0928	0.1376	0.2325	0.2325	0.0928	
19. Annualized Direct Investment Cost Of Equipment (Row 12 * Row 18)	$350.56	$235.66	$3,594.93	$165.33	$43.60	$447.56	
20. Total Annualized Direct Investment Cost Of Equipment (Row 20: Σ(Columns 2 – 7))							$4,838
21. Labor Costs For Implementing Intervention In 2002 Dollars							$500.00
22. Total Direct Cost Of Intervention Including Labor Costs (Row 20 + Row 21)							$5,338
Medical Care Costs							
23. Annual Medical Care Costs In 2002 Dollars After Intervention							$0.00
24. Annual Medical Care Costs In 2002 Dollars Before Intervention (Row 27 + Row 30)							$1,010
25. Number Of Employees Suffering From Acute Low Back Pain	6	Workers					
26. Medical Care Cost Per Acute Case	$168.29						
27. Total Medical Care Cost For Acute Cases	$1,009.76						
28. Number Of Employees Suffering From Chronic Low Back Pain	0	Workers					
29. Medical Care Cost Per Chronic Case	$0.00						
30. Total Medical Care Cost For Chronic Cases	$0.00						
31. Total Avoided Annual Medical Care Costs (Row 24 – Row 23)							$1,010
32. Net Cost Net Of Medical Care Costs (Row 22 – Row 31)							$4,328
33. Value of Lost Work Time After Intervention							$0.00
34. Value Of Lost Work Time Before Intervention Due To Lower Efficiency (Row 35 * Row 36 * Row 38 * Row 41)							$2,160
35. Number Of Workers With Acute LBP Before Intervention	6	Workers					
36. Average Duration Of Illness	30	Days					
37. Number Of Sick Days Due To LBP	0	Days					
38. Number Of Hrs/Day	8	Hours					
39. Reduced Efficiency	15	Percent					
40. Average Wage Rate Per Hour	$10.00						
41. Productivity Loss Per Injured Worker Per Hour (0.15 * Row 40)	$1.5						
42. Adjusted Wage Rate After Loss In Productivity By 15% (Row 40 – Row 41)	$8.50						
43. Total Avoided Annual Loss In Productivity (Row 34 – Row 33)							$2,160
44. Net Cost Net Of Medical Care Costs And Work Time Loss (Row 22 – Row 31 – Row 43)							$2,168
45. Cost Of Intervention Per Employee Net Of Medical Care Costs And Work Time Loss (Row 44 ÷ Row 52)							$17.62
Enhancement In Productivity							
46. Enhancement In Productivity For All Workers Subjected To Intervention	10%						
47. Productivity Gain Per Worker (0.10 * Row 40)	$1.00						

Table 1 (*continued*)

1	2	3	4	5	6	7	8
Enhancement In Productivity							
48. Adjusted Wage Rate After Increases In Productivity By 10% (Row 40 + Row 47)	$11.00						
49. Average Number Of Workers Subjected To Intervention	38	Workers					
50. Total Annual Gain In Productivity (52 weeks * 40 hours per week * Row 47 * Row 48)							$79,040
51. Annualized Net-Cost Taking Into Account Enhancement In Productivity (Row 22 – Row 31 – Row 43 – Row 50)							-$76,872
52. Total Number of Employees	123	Workers					
53. Annualized Net-Cost Taking Into Account Enhancement In Productivity Per Employee (Row 51 ÷ Row 52)							−$625
54. Annualized Cost Savings per Worker (Abs. Value of Row 53)							$625
55. Benefit–to–Cost Ratio							15.40

Labor Costs Included training Costs On Physical Therapist For Pre-shift Exercise and Stretching.
The market rate of interest as a proxy for the opportunity cost of capital was taken as 7 percent.
Average Duration of Illness for acute and sub acute LBP has been taken as 6 weeks (30 working days).
The effectiveness of the interventions was reported to be 100%.

consistent with the average loss in productive time of 5.2 hrs per week for LBP (Stewart, Ricci, Chee, Morganstein, & Lipton, 2003). We assumed an average duration of acute LBP to be six weeks (30 working days). For the six workers, we estimated a value of lost work time due to lower efficiency as $2,160. The computations were performed by adjusting the average wage rate to $8.50 (row 42 in Table 1) to reflect the lower efficiency during that period. Hence the total avoided annual loss in productivity was $2,160. This brought down the total annualized net-costs of intervention to $2,168 and a net-cost of intervention per employee net of medical care costs and work time loss to $17.62.

However, one of the most beneficial effects of these interventions was reflected in an enhancement in productivity for all workers that were subjected to the interventions, which was reported by the company official as 10%. The total gain in productivity estimated by our model was $79,040. We assumed that the current average wage rate of the worker represented a typical value of his/her marginal productivity. The net-cost after taking into account this enhancement was $76,872 with the cost per employee at $624.98. In other words, there was a total net savings of $76,872 for the company as a whole and it resulted in a savings of $625 per worker.

3.2. Case study B

A major automotive supplier with 637 workers has instituted an office ergonomics program for the past 12 years. Employees affected included secretaries, engineers, engineering technicians, managers, and salespersons. With regard to reducing back discomfort, lumbar pads and backrests were made available to employees (Appendix, Table 2). Back school workshops were also conducted.

In the year prior to the interventions, 41 employees complained of back pain or discomfort. Of these, three cases were categorized as acute (0-6 weeks in duration). The average number of missed days reported by the company due to LBP was 20 days. The remaining 38 cases were relieved the same day as the intervention. That is, no further complaints were received from these individuals. In the 12 years since the interventions were first implemented, 12 workers reported back pain. However, no sick leave was taken due to the discomfort. Of these, 2 were acute cases, and 10 were relieved upon intervention.

Medical care costs totaled $286.74 prior to the intervention, and $191.16 after the intervention. Hence, the net cost for medical care was $95.58. Lost work time due to sick leave before the intervention was $4,800 (Row 40 in Table 2). The company estimated a productivity loss of 20% for employees in pain or discomfort. A total loss in work time due to reduced efficiency for employees not on sick leave was $3,984 (row 56). A 5% productivity improvement was reported, resulting from the ergonomic interventions.[4] The total gain in productivity was estimated as $62,400 for the 20 employees that were subjected to the interventions. The estimated net-cost after taking into account this enhancement was −$70,440, with the cost per employee at −$110.58. In other words, the ergonomic interventions resulted in an estimated cost savings of $110.58 per employee.

3.3. Case study C

During a four-year time period, a 1,500 worker automobile and truck body plant instituted ergonomic interventions in various assembly lines. These interventions included a number of engineering controls. Ergonomic dollies used for transporting cabs in the truck cab trim sub-assembly line were redesigned. The increased height of the dolly (with retractable step added for safety) reduced the amount of

[4] It was impossible to separate this productivity gain from other ergo improvements for upper extremity.

Table 2
Estimation Of Annualized Net Economic Costs Of Ergonomic Interventions For Reducing Low Back Pain — Case Study B

1	2	3	4
Direct Costs Of Investments On Interventions			
1. Type Of Equipment	Lumbar Pads	Back Rests	
2. Year Purchased	1997	1997	
3. Unit Price Of Equipment Purchased After Intervention	$20.00	$25.00	
4. Quantity Of Current Equipment Purchased	80	24	
5. Unit Price Of Item Adjusted To 2002 (Using CPI)	$22.42	$28.02	
6. Value Of Equipment Purchased After Intervention In 2002 Prices (Row 4*Row 5)	$1793.40	$672.52	
7. Purchase Year For Prior Equipment	0	0	
8. Unit Price Of Prior Equipment Purchased	$0.00	$0.00	
9. Quantity Of Prior Equipment Purchased	0	0	
10. Unit Price Of Prior Equipment Adjusted To 2002 (Using CPI)	$0.00		
11. Value Of Equipment Purchased Before Intervention In 2002 Prices (Row 9*Row 10)	$0.00	$0.00	
12. Additional Direct Investment Cost In 2002 $ (Row 6 – Row 11)	$1793.40	$672.52	
13. Expected Life Of Equipment (Years)	10	10	
14. Salvage Value	$0.00	$0.00	
15. Net Of Savage Value (Row 12 – Row 15)	$1793.40	$672.52	
16. Depreciation (Using Formula)	$121.309	$45.49	
17. Rate Of Depreciation (Row 16 ÷ Row 15)	0.0676	0.0676	
18. Capital Recovery Factor (Interest Rate 7%+Row 17)	0.14	0.14	
19. Annualized Direct Investment Cost Of Equipment (Row 15*Row 12)	$246.85	$92.57	
20. Total Annualized Direct Investment Cost Of Equipment (Row 19: Σ(Columns 2 and 3))			$339.42
21. Other Costs For Implementing Intervention In 2002 Dollars			$500.00
22. Total Direct Cost Of Intervention Including Labor Costs (Row 20+Row 21)			$839.42
Medical Care Costs			
23. Annual Medical Care Costs In 2002 Dollars After Intervention (Row 26)			$191.16
24. Number Of Workers Suffering From Acute Low Back Pain	2	Workers	
25. Medical Care Cost Per Acute Case	$95.58		
26. Total Medical Care Cost For Acute Cases	$191.16		
27. Annual Medical Care Costs In 2002 Dollars Before Intervention (Row 30)			$286.74
28. Number Of Workers Suffering From Acute Low Back Pain	3	Workers	
29. Medical Care Cost Per Acute Case	$95.58		
30. Total Medical Care Cost For Acute Cases	$286.74		
31. Total Avoided Annual Medical Care Costs (Row 27 – Row 23)			$95.58
32. Net Cost Net Of Medical Care Costs (Row 22 – Row 31)			$743.84
33. Cost Of Intervention Net Of Medical Care Costs Per Employee (Row 32 ÷ Row 66)			$1.17
34. Value Of Lost Work Time Due To Sick Leave After Intervention			$0.00
35. Number Of Missed Days Of Work	0	Days	
36. Value Of Lost Work Time Due To Sick Leave Before Intervention (Row 37*Row 38*Row 39)			$4,800.00
37. Number Of Missed Days Of Work	20	Days	
38. Average Wage Rate	$30.00		
39. Number Of Hrs/Day	8	Hours	
40. Total Avoided Annual Value Of Lost Work Time Due To Sick Leave (Row 36 – Row 34)			$4,800.00
41. Value Of Lost Work Time Before Intervention Due To Lower Efficiency			
42. Total Number Of Days Of Reduced Efficiency Due To Acute LBP For All Workers (See Notes Below)	45	Days	
43. Number Of Hours Per Work Day	8	Hours	
44. Reduced Efficiency	20	Percent	
45. Average Wage Rate Per Hour	$30.00		
46. Productivity Loss Per Injured Worker Per Hour (0.2*Row 45)	$6.00		
47. Adjusted Wage Rate After Loss In Productivity By 20% (Row 45 – Row 46)	$24.00		
48. Total Loss Work Time Due To Reduced Efficiency From Acute LBP (Row 42*Row 43*Row 46)	$2160.00		
49. Total Number Of Days Of Reduced Efficiency Due To Sub Acute LBP For All Workers (See Notes Below)	38	Days	
50. Reduced Efficiency	20	Percent	
51. Number Of Hours Per Work Day	8	Hours	
52. Average Wage Rate Per Hour	$30.00		
53. Productivity Loss Per Injured Worker Per Hour (0.2*Row 52)	$6.00		
54. Adjusted Wage Rate After Loss In Productivity By 20% (Row 52 – Row 53)	$24.00		
55. Total Loss Work Time Due To Reduced Efficiency From Sub Acute LBP (Row 49*Row 51*Row 53)			$1824.00
56. Total Value Of Lost Productivity Due To Reduced Efficiency (Row 48+Row 55)			$3984.00
57. Net Cost Net Of Medical Care Costs And Work Time Loss (Row 22 – Row 31 – Row 40 – Row 56)			−$8040
58. Total Number Of Employees	637	Employees	
59. Cost Of Intervention Per Employee Net Of Medical Care Costs And Work Time Loss (Row 57 ÷ Row 58)			−$12.62

Table 2 (*continued*)

1	2	3	4
Enhancement in Productivity			
60. Enhancement In Productivity For All Workers Subjected To Intervention	5%		
61. Productivity Gain Per Worker (0.05*Row 52)	$1.50		
62. Adjusted Wage Rate After Increases In Productivity By 5% (Row 52+Row 61)	$31.50		
63. Average Number Of Workers Subjected to Intervention	20	Workers	
64. Total Annual Gain In Productivity (52 weeks*40 hours per week*Row 61*Row 63)			$62,400.00
65. Annualized Net-Cost Taking Into Account Enhancement In Productivity (Row 22 − Row 31 − Row 40 − Row 56 − Row 64)			−$70,440
66. Total Number of Employees	637	Employees	
67. Annualized Net-Cost Taking Into Account Enhancement In Productivity Per Employee (Row 65 ÷ Row 66)			−$110.58
68. Cost Savings Per Worker			$110.58
69. Benefit-to-Cost Ratio			84.9

There was a productivity loss of 20% for all employees who are in pain or discomfort. There were 3 workers who had on average symptoms from 0–6 weeks. For estimation purposes we have taken the mid point of duration of illness to be 3 weeks (15 working days). The other 38 workers had symptoms only for 1 day.

There are 41 workers who were subject to back pain in the most recent year. However, the number of workers who were subject to back pain interventions on an average over the past 12 years is 20.

bending required in assembly tasks (National Safety Council, 2003). In other lines, lift and tilt tables were installed, allowing adjustment of workstation heights. Mechanical lift assists and various platforms and risers reduced loads and awkward back postures of employees. Annualized equipment and labor cost was $ 512,657 (row 22 of Table 3, Appendix).

In the three years prior to the intervention, an annual average of 11.3 employees suffered from short duration back pain, and on average 4 cases were chronic. The average annual number of missed days of work due to back pain was 693. In the three years following the implementation of the interventions, back pain was greatly reduced. An annual average of 3.3 acute cases occurred, with an annual average of one sick day.

Avoided medical care costs due to the intervention were estimated at $16,280 (row 37 of Table 3), while avoided sick leave costs were $121,792 (row 47 of Table 3). The enhancement in productivity was reported at 40%. The company reported that after intervention the average time required for all workers subjected to the intervention decreased from 80 hours to 57 hours per unit. The total gain in productivity was $2,708, 992 (row 54 of Table 3). The net-cost after taking into account this enhancement was −$2,334,409 with the cost per employee at −$1,556. In other words, estimated cost savings per worker was $1,556.

3.4. Sensitivity analysis

Since there is considerable uncertainty in the data and parameters that we used to estimate the net-cost of interventions, we performed sensitivity analysis on the results on cost savings with respect to two crucial parameters: (a) interest rate to represent the long run opportunity cost of capital to estimate the annualized investment costs of interventions; and (b) productivity enhancement coefficient that essentially represents the advanced technological aspects of mainly engineering control interventions. We perturbed the above two parameters, interest rate (5% to 10%) and productivity enhancement coefficients (5% to 25% for Case Studies A and B and 10% to 50% for Case Study C) and solved the model with the perturbed values of these parameters.

We find that both interest rates and productivity enhancements are critical variables in determining the net costs of the interventions. Sensitivity analyses show that the direction of the net savings results is robust with respect to changes in these parameters although their magnitudes vary. In other words, the cost savings remain positive in spite of our different assumptions with respect to varying rates of interest and productivity. However, the sensitivity results presented in the relevant figures show that the variability in net-costs is much more pronounced with respect to productivity improvements compared to interest rate changes. The annual cost savings almost double with an increase in productivity by 5 percentage points. However, when the borrowing costs double, the cost savings are reduced marginally. Hence, the results of the case studies clearly reveal that the productivity enhancement characteristic of the interventions is a very crucial component in making these investments on interventions profitable for the company.

4. Discussion and conclusion

Our study provides a simple transparent framework to estimate the net-costs of investments on ergonomic interventions at the company level to reduce occupational morbidity. It illustrates the framework with three case studies. The particular formulation of the model was based on several other existing cost benefit frameworks that are available in the literature and was adapted to the data that were readily made available by three companies that had introduced such interventions over a number of years.

We are not aware of any study of ergonomic interventions that derive net-costs, hence our results are not directly

Table 3
Estimation Of Annualized Net Economic Costs Of Ergonomic Interventions For Reducing Low Back Pain — Case Study C

1	2	3	4	5	6	7
Direct Costs Of Investments On Interventions						
1. Type Of Equipment	Dolly's	Lift/Tilt Tables	Risers	Lift Assist	Marker Light Platform	
2. Year Purchased	2000	2000	2000	2000	2000	
3. Unit Price Of Equipment Purchased After Intervention	$1,917.00	$3,000.00	$300.00	$15,000.00	$1,000.00	
4. Quantity Of Current Equipment Purchased	85	12	47	9	1	
5. Unit Price Of Item Adjusted To 2002 dollars (using CPI)	$2,002.72	$3,134.15	$313.41	$15,670.73	$1,044.72	
6. Value Of Equipment Purchased After Intervention In 2002 Prices (Row 4 * Row 5)	$17,0231.16	$3,7609.76	$1,4730.49	$14,1036.59	$1,044.72	
7. Purchase Year For Prior Equipment	1979	0	0	1979	1979	
8. Unit Price Of Prior Equipment Purchased	$1,000.00	$0.00	$0.00	$2,000.00	$200.00	
9. Quantity Of Prior Equipment Purchased	85	0	0	4	1	
10. Unit Price Of Prior Equipment Adjusted To 2002 (using CPI)	$2,477.96	$0.00	$0.00	$4,955.92	$495.59	
11. Value Of Equipment Purchased Before Intervention In 2002 Prices (Row 9 * Row 10)	$21,0626.72	$0.00	$0.00	$19,823.69	$495.59	
12. Additional Direct Investment Cost (In 2002 $) (Row 6 – Row 11)	−$40,395.56	$37,609.76	$14,730.49	$12,1212.89	$549.12	
13. Expected Life Of Equipment (Years)	25	10	30	30	30	
14. Salvage Value	$0.00	$0.00	$0.00	$0.00	$0.00	
15. Net Of Savage Value (Row 12 – Row 14)	−$40,395.56	$37,609.76	$14,730.49	$12,1212.89	$549.12	
16. Depreciation (using formula)	−$596.89	$2544.02	$145.74	$1199.26	$5.43	
17. Rate Of Depreciation (Row 16 ÷ Row 15)	0.0148	0.0676	0.0099	0.0099	0.0099	
18. Capital Recovery Factor (Interest Rate 7% + Rate Of Depreciation)	0.0848	0.1376	0.0799	0.0799	0.0799	
19. Annualized Additional Direct Investment Cost Of Equipment (Row18* Row12)	−$3424.58	$5176.70	$1176.88	$9684.16	$43.87	
20. Total Annualized Direct Investment Cost Of Equipment (Row 19: Σ(Columns 2 – 6))						$12,657
21. Labor Costs For Implementing Intervention In 2002 Dollars						$500,000
22. Total Direct Cost Of Intervention Including Labor Costs (Row 20 + Row 21)						$512,657
Medical Care Costs						
23. Annual Medical Care Costs In 2002 Dollars After Intervention (Row 26 + Row 29)						$1,462
24. Number Of Employees Suffering From Acute Low Back Pain	3.33	Workers				
25. Medical Care Cost Per Acute Case in 2002 dollars	$438.57					
26. Total Medical Care Cost For Acute Cases (Row 24 * Row 25)	$1,461.90					
27. Number Of Employees Suffering From Chronic Low Back Pain	0.00	Workers				
28. Medical Care Cost Per Chronic Case	$3,193.25					
29. Total Medical Care Cost For Chronic Cases (Row 27 * Row 28)	$0.00					
30. Annual Medical Care Costs In 2002 Dollars Before Intervention (Row 33 + Row 36)						$17,742
31. Average Number Of Employees Suffering From Acute Low Back Pain	11.33	Workers				
32. Medical Care Cost Per Acute Case	$438.57					
33. Total Medical Care Cost For Acute Cases (Row 31 * Row 32)	$4,969.01					
34. Average Number Of Employees Suffering From Chronic Low Back Pain	4	Workers				
35. Medical Care Cost Per Chronic Case	$3,193.25					
36. Total Medical Care Cost For Chronic Cases (Row 34 * Row 35)	$12,773.01					
37. Total Annual Avoided Medical Care Costs (Row 30 – Row 23)						$16,280
38. Net Cost Net Of Medical Care Costs (Row 22 – Row 37)						$496,377
39. Value Of Lost Work Time After Intervention Due To Sick Leave (Row 40 * Row 41 * Row 42)						$176
40. Average Number Of Sick Days Due To LBP (Acute And Chronic Together) For All Sick Workers	1	Day				
41. Number Of Hrs/Day	8.00	Hours				
42. Average Wage Rate Per Hour	$22					
43. Value Of Lost Work Time Before Intervention Due To Sick Leave (Row 44 * Row 45 * Row 46)						$121,968
44. Average Number Of Sick Days Due To LBP (Acute And Chronic Together) For All Sick Workers	693.00	Days				
45. Number Of Hrs/Day	8.00	Hours				

Table 3 (*continued*)

1	2	3	4	5	6	7
Medical Care Costs						
46. Average Wage Rate Per Hour	$22.00					
47. Total Avoided Annual Loss In Work time Due to Sick Leave (Row 43 – Row 39)						$121,792
48. Net Cost, Net Of Medical Care Costs And Work Time Loss (Row 22 – Row 37 – Row 47)						$374,585
49. Cost Of Intervention Per Employee Net Of Medical Care Costs And Work Time Loss (Row 48 ÷ Row 56)						$250
Enhancement in Productivity						
50. Enhancement In Productivity For All Workers Subjected To Intervention					40%	
51. Productivity Gain Per Worker (0.40 * Row 46)					$8.8	
52. Adjusted Wage Rate After Increases In Productivity By 40% (Row 46 + Row 51)					$30.80	
53. Number Of Workers Subjected to Intervention				148	Workers	
54. Total Annual Gain In Productivity (52 weeks * 40 hours per week * Row 51 * Row 53)						$2,708,992
55. Annualized Net-Cost Taking Into Account Enhancement In Productivity (Row 22 – Row 37 – Row 47 – Row 54)						−$2,334,409
56. Total Number of Employees	1500	Employees				
57. Annualized Net-Cost Taking Into Account Enhancement In Productivity Per Employee (Row 55 ÷ Row 56)						−$1556
58. Cost Savings Per Worker (Abs. Value Of Row 57)						$1556
59. Benefit-to-Cost Ratio						5.5

The labor costs include all costs related to the implementation of the intervention.
The market rate of interest as a proxy for the opportunity cost of capital was taken as 7 percent.
After the intervention productivity for all workers increased from 80 hours per unit to 57 hours per unit.

comparable with other studies. For comparability of our study with other cost-benefit analyses, we calculated a benefit-to-cost ratios for each of the case studies and it ranges from 5.5 (Case Study C) to 84 (Case Study B) and a ratio of 15 for Case Study A (Tables 1–3).

In terms of cost-benefit analysis, our results compare favorably with other published results. For instance, the Upjohn Institute study (DeRango et al., 2003) obtained a benefit-to-cost ratio for chair-with-training intervention of 25 based on a longitudinal, quasi-experimental design field study of office workers. An econometric study of participatory ergonomics (Lanoie & Tavenas, 1996) for packers at a warehouse of the Society des Alcohols du Quebec in Quebec City also reports that the program was profitable for the company. Consistent with our negative net-costs of ergonomic interventions are the four case studies (Kemmlert, 1996) that evaluate the costs of ergonomic improvements. These studies estimated gains from ergonomic improvements and reported that Swedish companies achieved a payback period for the investment between 1 to 4 months. A payback period of less than one year would imply negative net-costs according to our model. The cost-benefit analysis study of ergonomic programs for two case studies in the manufacturing sector in Australia (Oxenburgh, 1997) also reports similar payback periods of less than 1 year for workplace interventions, hence lends support to the results of our study. The back injury and cost data of both the control and intervention groups before and after a one year intervention program conducted in a northern California county in 1989–90 showed a net benefit of introducing back injury prevention program to be $161,108 with a 179% return on investment (Shi, 1993).

Our analysis throws considerable light on a number of important policy issues. Our net- cost estimates for the three case studies consistently show that ergonomic interventions applied appropriately can result in substantial cost savings for the companies.[5] Although we do not like to generalize on the basis of three case studies, our analyses show that it might be in the economic interest of management to take a more active role to prevent back pain. Results of our analysis also reveal that the greatest economic savings to employers come from the improvement in productivity that result from the advanced technological design of the ergonomic interventions. We find in the literature that improvements in ergonomics often result in improvements in productivity (and vice versa). In fact, greater output per worker is often a consequence of ergonomic interventions, whether through individual workstation redesign, or through implementing engineering controls at a more macro level (Hendrick, 1996, 2003). Ergonomic improvements to transportation equipment was successful in the South African forestry industry (Hendrick, 1996). Although these improvements cost $300 per unit, it also resulted in an

[5] We tried to omit ergonomic improvements targeted exclusively to the upper extremity (such as wrist rests in the office setting) from our cost estimates. However, certain interventions such as general ergonomics training are applied to both lower and upper extremities. Hence, certain costs attributed to low back pain prevention may be over-estimated.

increase in productivity of $826 per unit. Ergonomic improvements to the loading/unloading processes resulted in higher rates of sugar cane transport (Hendrick, 2003). In an Indonesian sugar factory, ergonomic interventions with a combination of other measures led to an enhancement in productivity (Manuaba, 1995).

While we have not considered the costs of back pain interventions from a societal point of view, we need to keep in mind that the productivity enhancement characteristics of the interventions might result in lay-offs and hurt the workers. In other words, comprehensive cost estimates from society's point of view need to include retraining costs (and other related costs such as placement and mobility allowances) for the displaced workers as well. Not using the interventions to avert layoffs is not a viable alternative because non-use of interventions would imply more injuries for the workers and the companies, with similar unfavorable consequences for both.

In our attempts to gather useful cost information, we have found that the retrospective gathering of cost data, even on interventions deemed effective by corporate innovators, proved to be extremely difficult. Although they supported the idea of our study, many company officials indicated that the cost of developing such data retrospectively was prohibitive.

We know that the magnitude of avoidable costs essentially depends on the degree of effectiveness of the interventions. Since our case studies are based primarily on pre- and post-intervention observational studies, there remains considerable uncertainty in our estimates of avoidable costs. Collection of effectiveness data with the help of prospective studies would help in mitigating these effects of uncertainty in our estimates.

Hence, we have concluded that it is essential to incorporate a protocol for collecting cost and effectiveness data in the standard operating procedures of ergonomists and companies introducing such innovations. A simple questionnaire incorporating the important aspects of the net-cost model is presented in Table A1 in the Appendix and the net-cost model can be solved using an Excel spreadsheet. It is our hope that prospective studies incorporating this questionnaire or an adapted version of it may be used to more completely ascertain the net-costs of ergonomic interventions. In the near future, we aim to validate the net-cost model for the monitoring and reporting of such data in a variety of industrial settings and in countries at various stages of economic development. Currently we are working with our partners in India and Brazil to pilot this approach.

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Appendix A

TABLE A1. Ergonomic Intervention Questionnaire

This questionnaire has been developed by a research team at the University of Massachusetts Lowell. This team at UMASS Lowell is trying to develop estimates of Net-Costs of interventions to reduce work related back pain for select sectors of the economy under the sponsorship of the World Health Organization. As an industry leader, we would be very grateful if you would kindly fill in the following questionnaire. The purpose of the survey is purely academic. The information you provide will be held in strict confidence and will be used for research purposes only.

1. Organization: _________ 2. Industry Title: _________ 3. SIC code: __________

4. Specific categories of low back pain interventions (please list): ___________________________________

Our model will be based on annualized figures. We realize that your available statistics may take into account several years of data. Please fill in the appropriate time period that your statistics cover (in years or months) so that we can convert them into annual estimates.

5. Year(s) low back pain interventions were implemented (Number of years in dates e.g. 2000-2002): _________

6. Number of employees that were subjected to the intervention (in each of these years): ____________

7. Were there any other interventions that were applied to prevent low back pain but not mentioned above?

Characteristics of Workers with Low Back Pain - We are interested in the type of work done by those employees who have suffered from low back pain and in the number of cases of low back pain in order to estimate the effectiveness of the interventions applied.

There are several different ways of specifying low back pain. What are the criteria you will be using to answer the following questions? (Examples of criteria include: employee reported symptoms of low back pain, employee had restricted duty, employee missed at least day of work due to low back pain, employee had an OSHA recordable incident, etc.)

8. What are the criteria for low back pain that you are using to fill out this questionaire ____________

9. Please list the job title of each low back pain sufferer before and after the intervention:

Job Title	B: before the intervention, A: after the intervention, BA: both before and after

Our model will be based on annualized figures. We realize that your available statistics may take into account several years of data. Please fill in the appropriate time period that your statistics cover (in years or months).

10. Number of employees per year that suffered from low back pain prior to the intervention:

Year	Nature of back pain Acute /Chronic	Number of employees	Number of missed days of work	Average wage of these employees

Notes: Acute Cases (0-12 weeks duration of pain and/or disability)
Chronic Cases (more than 12 weeks duration of pain and/or disability)

11. Number of employees per year that suffered from low back pain after the intervention:

Year	Nature of back pain Acute /Chronic	Number of employees	Number of missed days of work	Average wage of these employees

12. Did you observe any loss in productivity due to lost work time (clinical visits, pain, fatigue etc.) even when the worker did not miss the entire day of work? Yes/No

13. If the answer is "yes", to the above question, what would be the average percentage of lost work time (hours / injured worker) or percentage decrease in efficiency per worker during the duration of their illness? ________________

14. Did you observe an increase in productivity per worker in the entire workforce (even those without prior back pain) simply due to the implementation of the ergonomic intervention? Yes /No ______________

If so, what was the percentage increase in efficiency per worker subjected to the intervention?

Direct Costs of Intervention

We are interested in learning about the costs incurred by the company to apply the above intervention. We are assuming that this cost consisted of two components: equipment cost and cost of additional labor. We have formulated the following questions to get an estimate of the direct cost of applying the above-mentioned intervention to prevent low back pain.

15. Was there any equipment used in the low back pain intervention?

16. If so, please list the types of equipment (lifts, adjustable chairs, etc.) that were used in the intervention: Yes or No

Type of equipment	# Pieces required	Price per unit	Year purchased	Total equipment cost	Expected life of equipment	Total annual operating cost	Total maintenance cost

17. If similar equipment was being purchased before the application of the Intervention, what was the price?
(For example, if ergonomically designed adjustable chairs are now being purchased, what were the prices ofthe chairs that were being purchased before the intervention?)

Type of equipment	# Pieces required	Price per unit	Year purchased	Total equipment cost	Expected life of equipment	Total annual operating cost	Total maintenance cost

18. What were the total annual additional wages/salaries paid for implementing the intervention? ________

(Again we are only interested in the total additional wages/salaries paid by the company to administer thet intervention(s). Kindly specify the time period with the $ amount so that we can compute annual estimates). (Please include only the wages/ salaries of personnel that were involved in training, specialist management,surveillance, and monitoring, etc.)

19. What was the size of the workforce before the intervention? _____ employees during ______ (specify year or years)

20. What was the size of the workforce after the intervention? ______ employees during ______ (specify year or years)

21. Do you have any other comments? Are there any company costs associated with low back pain that wet have missed? If you are aware of the medical-care costs of the injured workers ñ please state the average medical carecosts per injured worker.

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