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Inserting cost effectiveness to the ergonomic equation when considering practical solutions

(Part II of two part paper)

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From a practical point of view, the cost effectiveness of ergonomic solutions is often questioned. Many times managers omit ergonomic solutions because of their high cost. This paper introduces a way to implement cost effective ergonomic solutions by coupling computer-aided design and predetermined motion time systems. This is done by generating a comparison between the operation times and body motions used in existing and safer work situations. We demonstrate using two case studies how solutions may impact operation times and stress, to which workers are subjected, which may be expressed in relaxation allowances required for resting and recovery. The 'final product' which may interest management the most, the ergonomic recommendations, is presented in easy to understand figures and numbers, including time to return on investment on relevant ergonomic solutions, which becomes possible when suggested improvements to work-situations are translated to time and cost.

Keywords: Work measurement; Pre-determined motion time systems; Relaxation allowances; Computer-aided design; Workplace design

1. Introduction

Awareness of ergonomics has grown over the preceding decades and today risk factors are quantified and judged based on quantitative data rather than on hunches (Laurig *et al*. 1985). Engineers responsible for the design of the work situation and tools are becoming less conservative and do not accept existing design as inevitable. Consequently, they now make more effort than before in designing in advance, or re-designing, work situations so that these match the operator's capabilities and take into consideration that the human operator can easily adapt to local stress, which may result in injury in the long run.

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In order to meet operator capabilities, it is important to quantitatively evaluate tasks. The scientific discipline that deals with quantitative task evaluation is time and motion study, which goes hand in hand with ergonomics in this sense. Ergonomics and work study techniques are alike in the following aspects:

- Both were developed in order to maximize work efficiency. Ergonomics is defined as the research of factors influencing efficiency of human work. Conversely, efficiency is maximized when a standard work method exists and performance time-standards are defined and are derived through the implementation of scientific approaches—work measurement techniques. Coupling the two means the work method must be based on minimal operation times, efforts and costs—improving work-efficiency.
- Both rely on the basics of motion study and motion economy (Barnes 1980). Although developed empirically, these principles are based on anatomical, biomechanical and physiological principles of the human body in direct correlation to the task.

In this sense, the basics of both disciplines are one as they aim to improve work efficiency through implementation of optimal motions in the work area. The proposed approach is unique by virtue of its intent to offer a complete design, computing results for existing work situations and forecasting results for improvements on a cost-based comparison, coupling ergonomic and work measurement techniques.

Typically, many ergonomic practitioners have a problem in visualizing the effect the changes made to the work station's design will have on working posture and operation times. In order to help them grasp the re-design's implication, a time-consuming mock-up phase, which should include time-study and ergonomic analysis, is often carried out. Today, computer-aided design (CAD) tools are available to assist in visualizing work situation safety (Gupta *et al.* 1997). Nevertheless, these tools are expensive and require many hours to model basic work situations (Ben-Gal and Bukchin 2002). When the complexity of motion is included in the work situation to be studied, the cost effectiveness of such tools is questionable. Moreover, when using software that supports human motion, operation times are an input, meaning a predetermined motion time system (PMTS) study ought to be made to predict times. A generalized process for using such immersive tools is not available in the literature but informative, yet specific case studies are presented.

2. Methodology

Once hazardous work elements are identified, using quantitative methods, as explained in the first part of this paper, ergonomic-driven improvements are suggested. Then, the cost of the ergonomic improvements is formulated for different re-design alternatives, enabling to make decisions on the basis of investment and return on investment in terms of savings from implementing ergonomic solutions. The different stages of the methodology are outlined in figure 1 and explained below.

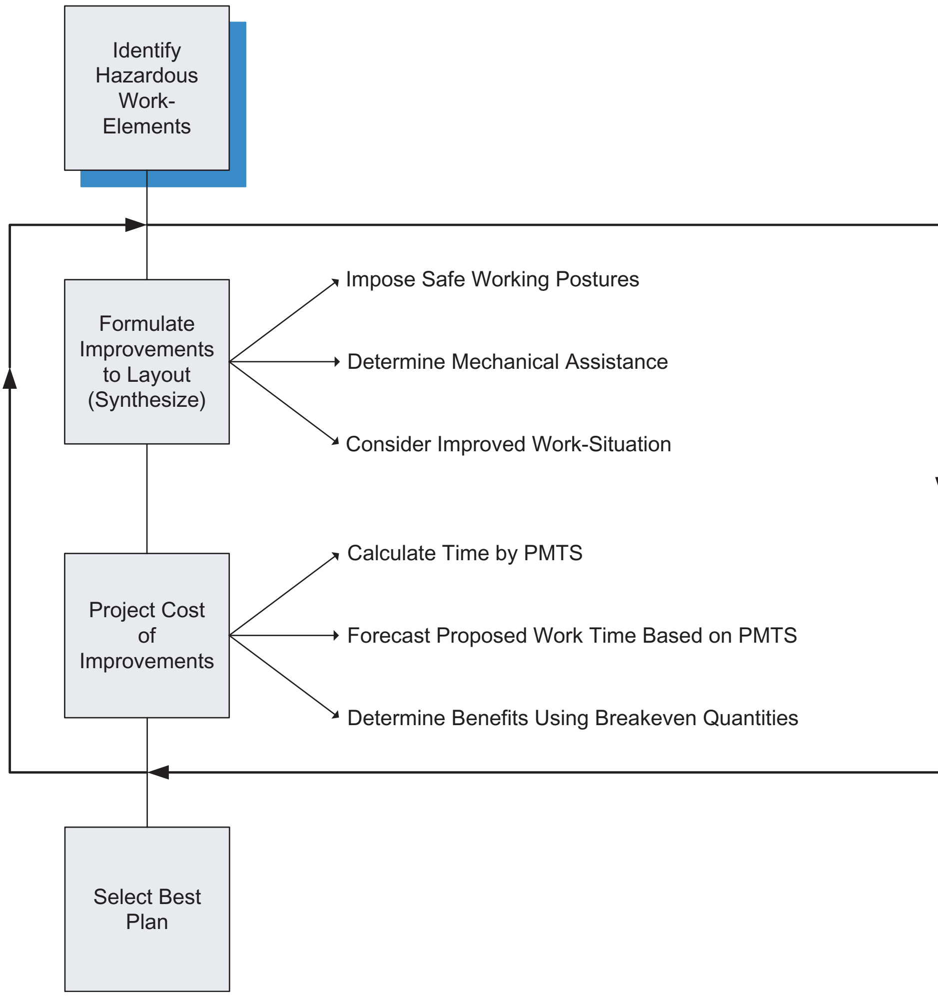

Figure 1. A generalized process for cost effective ergonomic design.

2.1 *Identifying hazardous work elements*

A procedure for identifying hazardous work elements was reviewed and enlarged upon in the first part of this paper. Once hazardous work elements are identified, they should be targeted for intervention and improvement.

2.2 *Layout design improvements*

Ergonomic improvements must be focused on preventing/relieving the identified hazards. As when considering designs and improvements for man–machine work situations, human limitations should be treated as constraints. Such constraints are considered in this paper to help drive the ergonomic improvement.

The following improvements should be made in accordance to the viewed hazards:

- *Back*. Continuous static effort on the lower back will ultimately cause lower back pain. This is minimized when keeping an erect back posture therefore leaning and bending elements should be improved or eliminated by allowing normal working heights.
- *Shoulder*. Continuous static effort on the shoulder is a cause of shoulder joint arthritis. This is minimized by keeping hands close to the body. Obstacles constraining normal posture of the shoulder should be changed.
- *Elbow*. Continuous static effort on the elbow may disrupt normal elbow functioning. In many cases this is caused by holding objects for too long or by exerting forces with upper extremities while keeping elbow straight. These can be avoided by changing distances in the work area so that elbows can be bent.
- *Wrist*. Continuous static effort on wrist can lead to disability of hand movements. This is caused by extended periods of ulnar deviation throughout the work cycle and repetitive snapping of the wrist in flexion and extension motions. The use of a tool can lead to bad posture. Maintaining correct working heights or purchasing tools that support good posture may improve such flaws. This is not easy when the same tool is used for several work elements, at different working heights.
- *Neck*. Continuous static effort of the neck will eventually cause pain in muscle groups around the neck. Keeping the neck in an upright posture will prevent fatigue to the muscles supporting the neck and avoid cumulative trauma disorders to this body part.

Our approach for visualizing the work situation uses common inexpensive tools. Visio is used as a sketching board, as this tool is common amongst industrial engineers. In order to achieve a correct working posture, initially a mannequin is positioned and its joint motions manipulated to reflect a common posture for the studied hazardous work element. Then, the heights of the work surfaces are manipulated to bring the upper body joint motions to a correct posture. Figure 2 emphasises the normal/neutral joint ranges (shaded in the figure) of upper body joint motions in the three views: sagittal, transverse and planar views. In the improved work situations joints are kept in the neutral areas, omitting bad posture.

When geometric constraints do not allow a match between the human operator and the work station, mechanical assistance, which may vary in performance, cost of operation, and the body postures it imposes, is the alternative solution. It will always be best to select a tool that facilitates a correct working posture, especially when a more ergonomic tool costs about the same and enables the same performance as other options. However, when there is a big difference in price and performance in the ergonomic work situation solution, the proposed improvements must be further evaluated.

Duration of static posture based on motion and time-study is essential when considering costly improvements in work situations. The analyst has to quantitatively reflect changes in the work situation if solid economic evaluation of re-design is required. For example, in lifting of bulky objects the root of bad posture is the working height. Ideally, objects should be kept at safe working heights (Saleem *et al.* 2003). In many cases, material is stacked and, therefore,

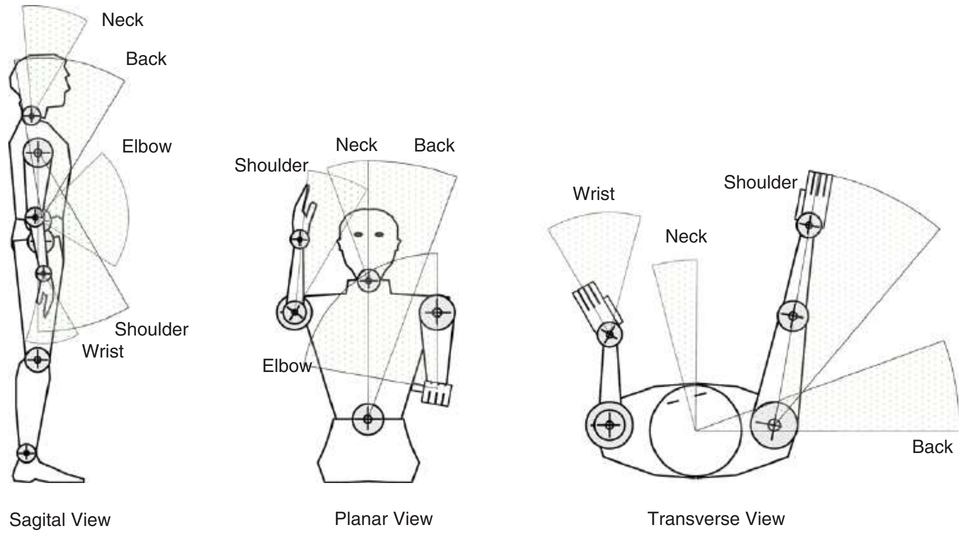

Figure 2. Proper postures of joint motions in sagittal, planar and transverse views.

bending heights change with advancing work cycles. Hence often, the practical approach is to purchase a lift for containers to reduce bending down to grasp objects. Another approach can be to flip the raw material to be piled vertical to the floor, enabling grasping with no bending. In both cases the analyst must project the savings in time and effort in comparison to the investment made.

2.3 *Project improvement costs*

In order to evaluate the cost of improvements, a PMTS study of the existing and proposed work situations must be made. The general approach is to quantitatively compare the existing and proposed work situation costs and to determine the benefits in making improvements through breakeven quantities of the number of work cycles to return investment. Formula (1) calculates the number of work cycles that are needed in order to return an invested cost in an ergonomic improvement. The invested costs essential to implement an ergonomic improvement are divided by the savings that result from implementing the improvement to the work cycle, which yields the number of cycles to breakeven on the investment.

$$BEQ_i = \frac{\text{Investment in Improvement } i}{\text{Savings from Improvement } i \text{ per work cycle}} = \frac{IC_i}{\Delta SCT \cdot LC} \tag{1}$$

$$\Delta SCT = SCT_{existing} - SCT_{proposed} \tag{2}$$

$$SCT = \sum_j \left[NOT_j \cdot \left(1 + RA_j\right)\right] \tag{3}$$

where:

BEQ_i	Break-even quantity of cycles returning investment on improvement *i*.
IC_i	Invested costs in implementing ergonomic improvement *i*.
ΔSCT	Difference between existing and proposed standard cycle times.
LC	Labour costs.
SCT	Standard cycle time of existing/proposed work situation.
NOT_j	Normal operation time of work element *j* from PMTS study.
RA_j	Resting allowances for work elements *j*.

Savings from implementing improvements are calculated as the difference between standard cycle times of existing and proposed work cycles multiplied by the labour costs, as exhibited in Formula (1). Formula (2) describes the difference in cycle time between the existing and proposed work situations. Cycle time calculation is shown in Formula (3), where normal times of work elements are multiplied by their corresponding resting allowances. Resting allowance tables are the most practical option when converting the ergonomic factor into time metrics and are, therefore, used. Normal operation times for existing and proposed work situations are calculated using PMTS.

2.4 *Selecting the best plan*

The best plan is not unequivocal, as it depends on managerial strategy for investing in improvement. Some improvements do return investment quite quickly, and consequently, are favoured. Others may be difficult for management to accept as they might lengthen operation times, slowing down production. Therefore, each ergonomic improvement should be communicated to management separately and not as a full solution. They should be ranked according to the rate of return on investment, for management to decide. In many cases, as sad as it sounds, management might choose not to ergonomically improve in order to produce with reduced cost. The implications of such decisions are expanded in the discussion section of this paper.

3. Results

The proposed approach for re-design was considered for the two case studies discussed in the first paper: (1) stacking aluminium profiles; and (2) assembling a bed-linen box.

3.1 *Case Study 1: Stacking aluminium profiles*

For this case study safe working heights were imposed on all work elements which include bending. Since the work element ‘arrange’ was identified as the most hazardous, an improvement to its working height was first formulated. In order to accommodate the work carried out during this work element, within the workers’ work envelope, the treatment cage must be of an adjustable height. This is done so as to take into consideration the fact that each stacked layer increases the working height. An automated mechanical lift, which automatically adjusts the height of the work, was considered. Although intuitive to visualize, figure 3 shows that omitting the crouching posture for this work element improved the workers' posture.

In order to determine the benefits of improvements, the time it takes to complete the existing work situation must be calculated using PMTS. The operation and sub-operation sequences, as well as the time and allowances for the existing work situation of stacking profiles, are shown in table 1. The sub-operation normal time and operation sequence are calculated using BasicMOST (Maynard Operation Sequence Technique). Time units are presented in time measurement units (TMUs) where one TMU equals 0.0006 minutes (Zandin 1990). Allowances were calculated using standard ILO (Israeli Labor Office) allowance tables for each work element. A normal time for performing the work cycle is 1.03 minutes (1724 TMU), where a standard time is 1.12 minutes (1870 TMU), leaving 0.09 minutes of rest per work cycle or 8.5%.

A forecasted work situation integrating Improvement 1, which includes purchasing a mechanical lift to accommodate the treatment cage, is presented in table 2. Such an improvement would eliminate four body motions from the BasicMOST sequence. In table 2 differences between the existing and proposed work situations are highlighted. At the bottom of table 2 savings and benefits from implementing such an improvement are calculated. Each work cycle 302 TMUs are saved ($302 = 151 \times 2$), that is, the time of two workers is saved. When translated into money using a \$20/hour labour cost, a total saving of \$22.3/workday is expected. Implementing Improvement 1 requires an investment of \$5000 and, therefore, a quantity of about 178 workdays is required for this improvement to break even.

Improvement 2 offers two more of the same \$5000 mechanical lifts (a total of \$10 000) to accommodate both left and right raw material cages. The work situation for this improvement is exhibited in table 3, where the savings and break even quantity are calculated and shown. Improvement 2 saves 84 TMUs per work

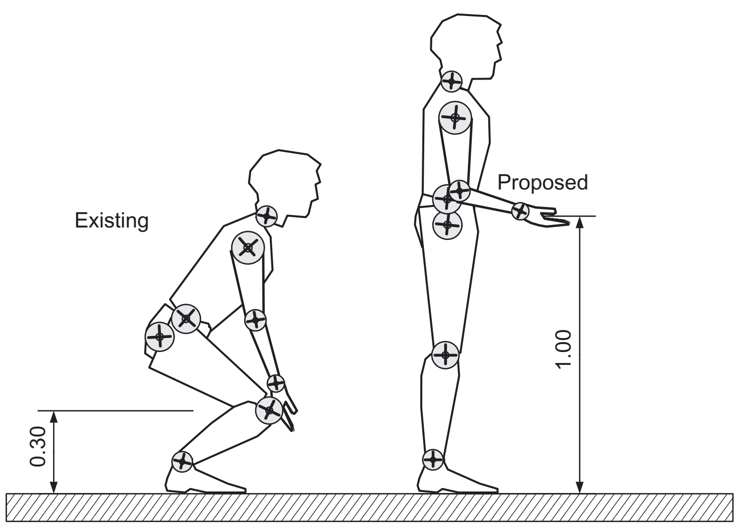

Figure 3. Improved work situation for crouching postures in Case Study 1.

Table 1. BasicMOST analysis of the existing work situation in Case Study 1.

Existing Work Situation for Case-Study 1 - Profile Arrangement

	BasicMOST Analysis								Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load from Left	Sub-Operation Sequence	A_6	B_3	G_3	A_6	B_3	P_1	A_1	1	350	9	382
	Partial Frequency	1	1	5	1	1	1	1				
Load from Right	Sub-Operation Sequence	A_3	B_3	G_3	A_3	B_3	P_1	A_1	1	290	9	316
	Partial Frequency	1	1	5	1	1	1	1				
Arrange	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_1	A_1	10	500	8	540
	Partial Frequency	1	1	1	1	1	1	1				
Position Dividers	Sub-Operation Sequence	A_3	B_6	G_1	A_{10}	B_3	P_6	A_6	1	510	9	556
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Qperatbn Sequence	A_0	B_0	G_0	A_1	B_3	P_6	A_6				
	Partial Frequency	1	1	1	1	1	1	1				
Prepare Raw Materials	Sub-Operation Sequence	A_3	B_3	G_1	A_0	B_0	P_0	A_0	0.2	74	4	77
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_6	B_3	G_1	A_{10}	B_6	P_1	A_3				
	Partial Frequency	1	1	1	1	1	1	1				
									Nornal Cycle-Time [TMU]:	**1,724**		
										Allowance per Cycle:	**8.5%**	
											Standard Cycle-Time [TMU]:	**1,870**

Table 2. BasicMOST analysis of the proposed work situation integrating Improvement 1 in Case Study 1.

Improvement 1: Purchasing a Mechanical Lift to Accomodate Treatment Cage

BasicMOST Analysis									Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load from Left	Sub-Operation Sequence	A_6	B_3	G_3	A_6	B_0	P_1	A_1	1	320	8	346
	Partial Frequency	1	1	5	1	1	1	1				
Load from Right	Sub-Operation Sequence	A_3	B_3	G_3	A_3	B_0	P_1	A_1	1	260	8	281
	Partial Frequency	1	1	5	1	1	1	1				
Arrange	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_1	A_1	10	500	6	530
	Partial Frequency	1	1	1	1	1	1	1				
Position Dividers	Sub-Operation Sequence	A_3	B_6	G_1	A_{10}	B_0	P_6	A_6	1	450	8	486
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_0	B_0	G_0	A_1	B_0	P_6	A_6				
	Partial Frequency	1	1	1	1	1	1	1				
Prepare Raw Materials	Sub-Operation Sequence	A_3	B_3	G_1	A_0	B_0	P_0	A_0	0.2	74	4	77
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_6	B_3	G_1	A_{10}	B_6	P_1	A_3				
	Partial Frequency	1	1	1	1	1	1	1				
								Normal Cycle-Time [TMU]:		**1,604**		
									Allowance per Cycle:		**7.2%**	
										Standard Cycle-Time [TMU]:		**1,719**

Calculation of Savings and Break Even Quantity for considering improvement 1	
Difference between existing and proposed Standard Cycle Times [TMU/Work-Cycle]	151
Difference between existing and proposed Normal Cycle Times [TMU/Work-Cycle]	120
Labour Costs per Hour	$20
Operational Savings in 8 Hour Work-Day	$22.33
Savings in Allowances in 8 Hour Work-Day	$5.79
Total Savings in 8 Hour Work-Day	**$28.12**
Invested Costs in improvement [$]	$5,000
BEQ (expressed in Work-Days):	**178**

Table 3. BasicMOST analysis of the proposed work situation integrating Improvement 2 in Case Study 1.

Improvement 2: Purchasing 2 Mechanical Lifts to Accomodate both left and Right Raw Material Cages

	BasicMOST Analysis								Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load from Left	Sub-Operation Sequence	A_6	B_0	G_3	A_6	B_3	P_1	A_1	1	320	8	346
	Partial Frequency	1	1	5	1	1	1	1				
Load from Right	Sub-Operation Sequence	A_3	B_0	G_3	A_3	B_3	P_1	A_1	1	260	8	281
	Partial Frequency	1	1	5	1	1	1	1				
Arrange	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_1	A_1	10	500	8	540
	Partial Frequency	1	1	1	1	1	1	1				
Position Dividers	Sub-Operation Sequence	A_3	B_6	G_1	A_{10}	B_3	P_6	A_6	1	510	9	556
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_0	B_0	G_0	A_1	B_3	P_6	A_6				
	Partial Frequency	1	1	1	1	1	1	1				
Prepare Raw Materials	Sub-Operation Sequence	A_3	B_0	G_1	A_0	B_0	P_0	A_0	0.2	62	4	64
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_6	B_0	G_1	A_{10}	B_6	P_1	A_3				
	Partial Frequency	1	1	1	1	1	1	1				
									Normal Cycle-Time [TMU]:	**1,652**		
										Allowance per Cycle:	**8.2%**	
											Standard Cycle-time [TMU]:	**1,787**

Calculation of Savings and Break Even Quantity for considering improvement 2	
Difference between existing and proposed Standard Cycle Times [TMU/Work-Cycle]	84
Difference between existing and proposed Normal Cycle Times [TMU/Work-Cycle]	72
Labour Costs [$/hour]	20
Operation Savings in 8 Hour Work-Day	$12.9
Savings in Allowances in 8 Hour Work-Day	$2.1
Total Savings in 8 Hour Work-Day	**$15.0**
Invested Costs in improvement [$]	$10,000
BEQ (expressed in Work-Days):	**667**

cycle, which results in $15 savings a day. Given the cost for this improvement, the investment will be returned within 667 workdays.

A third improvement imposes safe working heights on the divider box work, which in the existing work situation includes bending. Improvement 3 is inexpensive to implement and is estimated to cost $100. Table 4 presents the operation sequence which results from implementing this improvement. This improvement will shorten the cycle time by 115 TMUs and will produce a $21/day savings, which will return the invested cost within about 5 work days.

3.2 *Case Study 2: Bed-linen box assembly*

Table 5 shows a BasicMOST analysis for the existing work situation in assembling a bed-linen box. A normal time for performing the work cycle was found to be 5.71 minutes (9520 TMU). Allowances were calculated to be 11.8%, leading to a standard time of 6.39 minutes (10 647 TMUs), leaving 0.68 minutes of rest per work cycle.

From the results of our previous paper, screw fastening operations were found to be most hazardous. The observed poor posture for this work element in the filmed work situation was due to the need to operate a power tool on obstructed points in the assembly, as each corner is difficult to reach due to the box's geometry. A picture of this posture is shown in the previous paper in figure 8 (screw corner support) and is demonstrated here in figure 4 versus an improved posture. Improvement 1 suggested changing the operation sequence: first, screw the corner support to the long boards, laid flat on the workbench, prior to nailing the long boards to the short boards. This way the points where the screws need to be attached are not obstructed. In order to incorporate a correct working posture when handling the tool for this operation, the pistol-shaped screwdriver, used today, must be replaced with a vertical one.

Table 6 formulates the proposed Improvement 1 in BasicMOST. Changes in the operation sequence are highlighted in the proposed work sequence. Changing the operation sequence imposes more tool changing operations, which actually lengthens the operative work cycle. The better posture improves allowances for positioning the corner supports and in screwing these onto the long board. In addition, position motions are shortened for positioning the corner supports and the screwdriver, as the locations of positioning are easy to reach and not obstructed. A summary of Improvement 1 versus the existing work situation can be found at the bottom of table 6. The proposed work situation improves the standard time by 25 TMUs per work cycle, even though the normal time for the work cycles is lengthened by 20 TMUs. The total saving per workday is only $0.37. Taking a $20 per hour cost for the worker and an investment of $250 for the vertical screwdriver, this investment will be returned within 669 workdays.

Improvement 2 suggested using a sling in order to reduce the force required by the worker to overcome the weight of the power screwdriver, also presented in figure 4. Such an improvement to the work situation will reduce the allowances for the screwing operations by 2% and will not affect operation times. This will result in a 25.6 TMU improvement to the standard cycle time and $0.39 saving per workday. With an approximated cost of $150 for the sling, this improvement will be returned in 389 days. This improvement was not formulated in a separate table,

Table 4. BasicMOST analysis of the proposed work situation integrating Improvement 3 in Case Study 1.

Improvement 3: Adjusting Height of Divider Boxes

	BasicMOST Analysis								Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load from Left	Sub-Operation Sequence	A_6	B_0	G_3	A_6	B_3	P_1	A_1	1	320	9	349
	Partial Frequency	1	1	5	1	1	1	1				
Load from Right	Sub-Operation Sequence	A_3	B_3	G_3	A_3	B_3	P_1	A_1	1	290	9	316
	Partial Frequency	1	1	5	1	1	1	1				
Arrange	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_1	A_1	10	500	8	540
	Partial Frequency	1	1	1	1	1	1	1				
Position Dividers	Sub-Operation Sequence	A_3	B_0	G_1	A_{10}	B_3	P_6	A_6	1	450	8	486
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_0	B_0	G_0	A_1	B_3	P_6	A_6				
	Partial Frequency	1	1	1	1	1	1	1				
Prepare Raw Materials	Sub-Operation Sequence	A_3	B_3	G_1	A_0	B_0	P_0	A_0	0.2	62	4	64
	Partial Frequency	1	1	1	1	1	1	1				
	Sub-Operation Sequence	A_6	B_3	G_1	A_{10}	B_0	P_1	A_3				
	Partial Frequency	1	1	1	1	1	1	1				
									Normal Cycle-Time [TMU]:	**1,622**		
										Allowance per Cycle:	**8.2%**	
											Standard Cycle-Time [TMU]:	**1,755**

Calculation of Savings and Break Even Quantity for considering improvement 3	
Difference between existing and proposed Standard Cycle Times [TMU/Work-Cycle]	115
Difference between existing and proposed Normal Cycle Times [TMU/Work-Cycle]	102
Labour Costs [$/Hour]	20
Operational Savings in 8 Hour Work-Day	$18.6
Savings in Allowances in 8 Hour Work-Day	$2.4
Total Savings in 8 Hour Work-Day	**$21.0**
Invested Costs in improvement [$]	$100
BEQ (expressed in Work-Days):	**5**

Table 5. BasicMOST analysis of the existing work situation in Case Study 2.

Existing Work Situation for Case-Study 2 - Bed Linen-Box Assembly

	BasicMOST Analysis		Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load 2 long boards	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_3 A_{10} B_0 P_1 A_1 1 1 1 1 1 1 1	1	280	6	297
Load 2 short boards	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_3 A_{10} B_0 P_1 A_0 1 1 1 1 1 1 1	1	270	6	286
Position long board to short board	Sub-Operation Sequence Partial Frequency	A_6 B_0 G_3 A_1 B_0 P_6 A_0 1 1 2 2 1 2 1	4	1,040	10	1,144
Assemble long board to short board with 3 nails using nail gun	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_1 A_1 B_0 P_3 F_1 A_3 B_0 P_1 A_0 1 1 1 3 3 3 3 1 1 1 1	4	920	14	1,049
Load 2 rods	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_1 A_{10} B_0 P_1 A_0 1 1 1 1 1 1 1	1	250	4	260
Position rod to long board	Sub-Operation Sequence Partial Frequency	A_{10} B_0 G_1 A_3 B_0 P_3 A_0 1 1 1 1 1 1 1	4	680	5	714
Assemble rod to long board with one nail using nail gun	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_3 F_1 A_1 B_0 P_1 A_0 1 1 1 1 1 1 1 1 1 1 1	4	360	13	407
Change tool from nail gun to screwdriver	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 M_1 X_0 I_0 A_0 1 1 1 1 1 1 1	1	30	6	32
	Sub-Operation Sequence Partial Frequency	A_0 B_0 G_0 A_1 B_0 P_1 A_0 1 1 1 1 1 1 1	1	20	6	21
	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_3 A_0 1 1 1 1 1 1 1	1	60	6	64

(continued)

Table 5. Continued.

Existing Work Situation for Case-Study 2 - Bed Linen-Box Assembly

	BasicMOST Analysis		Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Position corner support	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_1 A_3 B_0 P_6 A_0 1 1 2 1 1 1 1	4	560	7	599
Assemble corner support with 4 screws using power screwdriver	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_3 F_3 A_1 B_0 P_1 A_0 1 1 1 4 4 4 4 1 1 1 1	4	1,280	13	1,446
Change tool from screwdriver to nail gun	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 M_1 X_0 I_0 A_0 1 1 1 1 1 1 1	1	30	6	32
	Sub-Operation Sequence Partial Frequency	A_0 B_0 G_0 A_1 B_0 P_1 A_0 1 1 1 1 1 1 1	1	20	6	21
	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_3 A_0 1 1 1 1 1 1 1	1	60	6	64
Load backboard	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_3 A_{10} B_0 P_3 A_0 1 1 1 1 1 1 1	1	290	7	310
Position backboard	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_3 A_1 B_0 P_6 A_0 1 1 1 1 1 1 1	1	130	10	143
Assemble backboard to boards and rods with 54 nails using nail gun	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_1 A_1 B_0 P_3 F_1 A_1 B_0 P_1 A_1 1 1 1 54 54 54 54 1 1 1 1	1	2,770	17	3,241
Unload backboard	Sub-Operation Sequence Partial Frequency	A_3 B_3 G_3 A_{16} B_3 P_3 A_{16} 1 1 1 1 1 1 1	1	470	10	517
			Normal Cycle-Time [TMU]:	**9,520**		
				Allowance per Cycle:	**11.8%**	
					Standard Cycle-Time [TMU]:	**10,647**

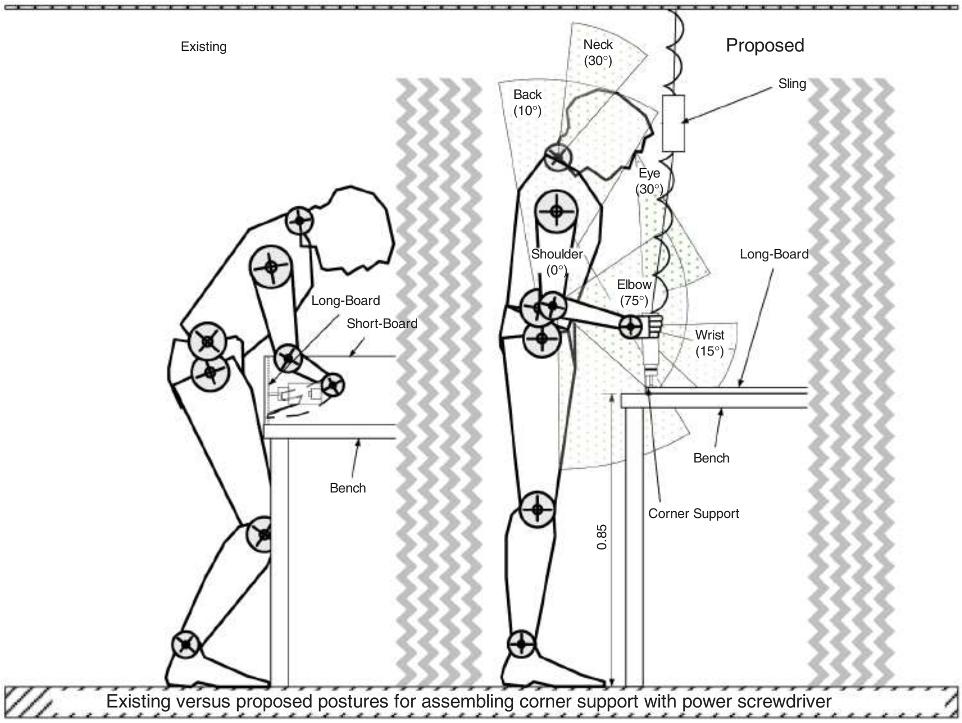

Figure 4. Existing and improved work postures for screwing corner supports.

as it does not impose any change in the operation sequence, but only alleviates stress on the worker and is expressed in allowances.

The second most hazardous work element is the long board to short board nailing operation, which is carried out using a power nail gun. In the existing work situation this operation is carried out with a problematic 90° supination, as exhibited in figure 5. Due to the geometry of the assembly, the operation cannot be improved straightforwardly, as done for the former work situation, without adding many motions to the work sequence, since this operation provides the assembly its initial shape. Nevertheless, for performing such an operation the worker is better off positioning the nail gun with a 90° pronation rather than supination, as shown in figure 5. Such an improvement (Improvement 3) is up to the plant's engineering team—they will have to re-educate the worker—and will not call for capital investment. Improvement 3 reduces allowances for these nailing operations by 1%, due to better posture, without changes in operation times. This will save 9.2 TMUs per work cycle, which is ~\$0.14 per workday. As no expenditure is required, such an improvement is favourable, yet is up to the worker to implement.

Improvements were considered for the backboard nailing operations as well. Improvement 4 suggested replacing the pistol-shaped nail gun with a vertical one, thereby allowing normal posture. Improvement 5 proposed keeping the pistol-shaped nail gun while inclining the work-surface by 20° to allow

Table 6. BasicMOST analysis for the proposed work situation integrating Improvement 1, including using a vertical screwdriver in corner support assembly and a change in operation sequence.

Improvement 1: Changing operation sequence (assembling corner support to long board before assembling long board with short board) and using vertical screwdriver to impose safe working posture

	BasicMOST Analysis		Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load 2 long boards	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_3 A_{10} B_0 P_1 A_1 1 1 1 1 1 1 1	1	280	6	297
Position corner support	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_1 A_3 B_0 P_3 A_0 1 1 2 1 1 1 1	4	440	5	462
Change tool from nail gun to screwdriver	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 M_1 X_0 I_0 A_0 1 1 1 1 1 1 1	1	30	6	32
	Sub-Operation Sequence Partial Frequency	A_0 B_0 G_0 A_1 B_0 P_1 A_0 1 1 1 1 1 1 1	1	20	6	21
	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_3 A_0 1 1 1 1 1 1 1	1	60	6	64
Assemble corner support to long board with 3 screws using power screwdriver	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_1 F_3 A_1 B_0 P_1 A_0 1 1 1 3 1 3 3 1 1 1 1	4	760	9	828
Load 2 short boards	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_3 A_{10} B_0 P_1 A_0 1 1 1 1 1 1 1	1	270	6	286
Change tool from screwdriver to nail gun	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 M_1 X_0 I_0 A_0 1 1 1 1 1 1 1	1	30	6	32
	Sub-Operation Sequence Partial Frequency	A_0 B_0 G_0 A_1 B_0 P_1 A_0 1 1 1 1 1 1 1	1	20	6	21
	Sub-Operation Sequence Partial Frequency	A_1 B_0 G_1 A_1 B_0 P_3 A_0 1 1 1 1 1 1 1	1	60	6	64

Position long board to short board	Sub-Operation Sequence	A_6 B_0 G_3 A_1 B_0 P_6 A_0	4	1,040	10	1,144
	Partial Frequency	1 1 2 2 1 2 1				
Assemble long board to short board with 3 nails using nail gun	Sub-Operation Sequence	A_3 B_0 G_1 A_1 B_0 P_3 F_1 A_3 B_0 P_1 A_0	4	920	14	1,049
	Partial Frequency	1 1 1 3 3 3 3 1 1 1 1				
Load 2 rods	Sub-Operation Sequence	A_{10} B_3 G_1 A_{10} B_0 P_1 A_0	1	250	4	260
	Partial Frequency	1 1 1 1 1 1 1				
Position rod to long board	Sub-Operation Sequence	A_{10} B_0 G_1 A_3 B_0 P_3 A_0	4	680	5	714
	Partial Frequency	1 1 1 1 1 1 1				
Assemble rod to long board with one nail using nail gun	Sub-Operation Sequence	A_1 B_0 G_1 A_1 B_0 P_3 F_1 A_1 B_0 P_1 A_0	4	360	13	407
	Partial Frequency	1 1 1 1 1 1 1 1 1 1 1				
Change tool from nail gun to screwdriver	Sub-Operation Sequence	A_1 B_0 G_1 M_1 X_0 I_0 A_0	1	30	6	32
	Partial Frequency	1 1 1 1 1 1 1				
	Sub-Operation Sequence	A_0 B_0 G_0 A_1 B_0 P_1 A_0	1	20	6	21
	Partial Frequency	1 1 1 1 1 1 1				
	Sub-Operation Sequence	A_1 B_0 G_1 A_1 B_0 P_3 A_0	1	60	6	64
	Partial Frequency	1 1 1 1 1 1 1				
Assemble corner support with 1 screw to short board using power screwdriver	Sub-Operation Sequence	A_1 B_0 G_1 A_1 B_0 P_3 F_3 A_1 B_0 P_1 A_0	4	440	13	497
	Partial Frequency	1 1 1 1 1 1 1 1 1 1 1				
Change tool from screwdriver to nail gun	Sub-Operation Sequence	A_1 B_0 G_1 M_1 X_0 I_0 A_0	1	30	6	32
	Partial Frequency	1 1 1 1 1 1 1				
	Sub-Operation Sequence	A_0 B_0 G_0 A_1 B_0 P_1 A_0	1	20	6	21
	Partial Frequency	1 1 1 1 1 1 1				
	Sub-Operation Sequence	A_1 B_0 G_1 A_1 B_0 P_3 A_0	1	60	6	64
	Partial Frequency	1 1 1 1 1 1 1				

(*continued*)

Table 6. Continued.

Improvement 1: Changing operation sequence (assembling corner support to long board before assembling long board with short board) and using vertical screwdriver to impose safe working posture

	BasicMOST Analysis		Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load backboard	Sub-Operation Sequence Partial Frequency	A_{10} B_3 G_3 A_{10} B_0 P_3 A_0 1 1 1 1 1 1 1	1	290	7	310
Position backboard	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_3 A_1 B_0 P_6 A_0 1 1 1 1 1 1 1	1	130	10	143
Assemble backboard to boards and rods with 54 nails using nail gun	Sub-Operation Sequence Partial Frequency	A_3 B_0 G_1 A_1 B_0 P_3 F_1 A_1 B_0 P_1 A_1 1 1 1 54 54 54 54 1 1 1 1	1	2,770	17	3,241
Unload backboard	Sub-Operation Sequence Partial Frequency	A_3 B_3 G_3 A_{16} B3 P_3 A_{16} 1 1 1 1 1 1 1	1	470	10	517
			Normal Cycle-Time [TMU]:	**9,540**		
				Allowance per Cycle:	**11.3%**	
					Standard Cycle-Time [TMU]:	**10,622**

Calculation of Savings and Break Even Quality for considering improvement 1	
Difference between existing and proposed Standard Cycle Times [TMU/Work-Cycle]	25
Difference between existing and proposed Normal Cycle Times [TMU/Work-Cycle]	−20
Labour Costs per Hour	$20
Operational Savings in 8 Hour Work-Day	−$0.30
Savings in Allowances in 8 Hour Work-Day	$0.67
Total Savings in 8 Hour Work-Day	**$0.37**
Invested Costs in improvement [$]	$250
BEQ (expressed in Work-Days):	**669**

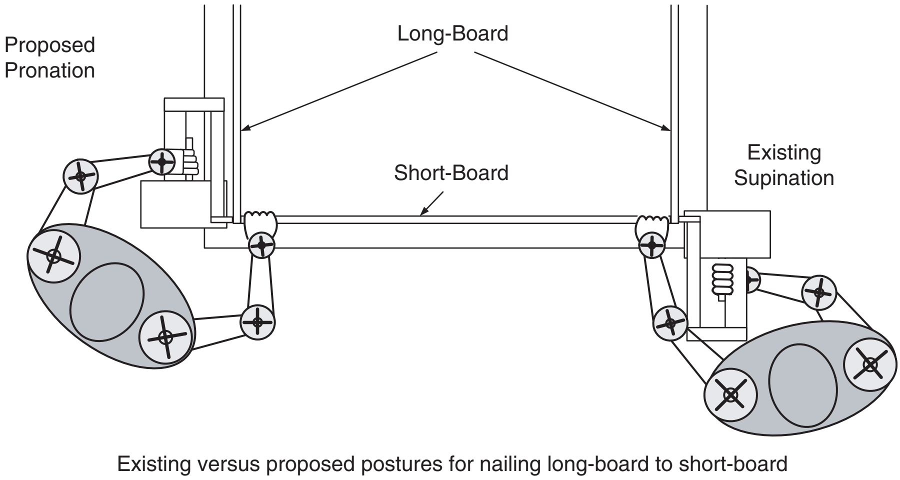

Figure 5. Existing and improved work-situations in nailing operations.

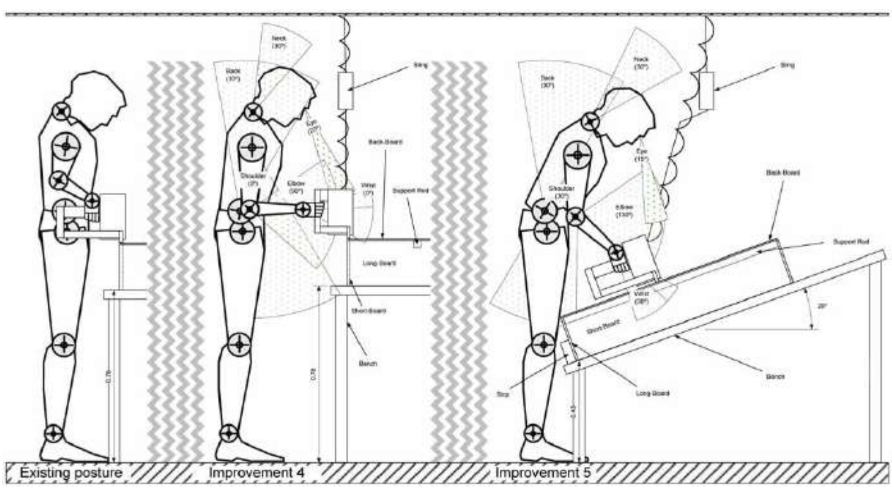

Figure 6. Existing and improved work postures for back-board nailing.

correct working postures. In the nailing backboard operations, the worker uses a pistol tool that is directed perpendicular to the ground, causing ulnar deviation. Moreover, since the backboard is located at about elbow height, and does not take into consideration the tool the operator holds, shoulder adduction is also inevitable. Figure 6 presents the existing work posture and Improvements 4 and 5 for imposing correct work posture to backboard nailing. Improvement 4 does not influence operation sequence but only working posture in this operation. This will reduce allowances by 2% for backboard nailing operations, resulting in a saving of 55.4 TMU per work cycle, or of \$0.83 per workday while using an hourly labour cost of \$20. Replacing the pistol-shaped tool with a vertical tool will likely cost approximately \$250, which will be returned in about 299 workdays. Table 7 formulates the BasicMOST sequence for Improvement 5, which includes reorientation operations for the box since the inclination will impose poor working posture while attempting to work on the high side of the assembly, which is about 35 centimetres higher. Reorientation operations are highlighted in table 7, which also include extra operations for grasping and releasing tools at hand in both backboard nailing operations and screwing operations. This improvement will reduce stress, expressed in a 2% reduction of allowances for the backboard nailing operations. Our suggestion to incline the work surface requires a \$25 investment that will never be paid off as the standard cycle time is lengthened by 524 TMUs.

Improvement 6 is similar to Improvement 2, which includes purchasing a sling to overcome the weight of the nail gun. As in Improvement 2, this will cost \$150 and will result in less stress in nailing operations, expressed in a 2% allowance reduction for long to short board nailing, support rod nailing and backboard nailing. A total of 81 TMUs per cycle will be saved, which will result in a savings of \$1.23 per workday that will return in approximately 122 workdays.

Finally, Improvement 7, which is operational in nature, recommended an extra separate pneumatic installation for the screwdriver and nail gun. In the existing work situation the worker, twice per work-cycle, switches the pneumatic power, alternating the nail gun with the screwdriver and vice versa. This installation is estimated to cost abut \$350 and will reduce the cycle time by 220 TMUs (each tool change takes up 110 TMUs). This improvement will result in a \$3.58 reduction in cost per workday and will return in 98 workdays.

4. Discussion

The proposed improvements in Case Studies 1 and 2, respectively, are summarized in tables 8 and 9. Management can act to implement improvements through an initial investment and expect to get a return on their investment. The tables show that the amount required to invest is not the only factor when considering implementing an improvement. Improvements to operation times and decreased stress to the operator (expressed in reduced fatigue allowance times) may also influence decisions about implementing improvements.

In the Results section the return on investment was calculated in terms of investment versus savings in time, which are converted to money using an hourly cost. The formulas we used in this paper consider the cost of the ergonomic factor through allowances for the work cycle, which are usually reduced when considering ergonomic improvements. In cases where ergonomic improvements propose a capital investment and decreased standard throughput, the improvement will never breakeven (as exhibited in Improvement 5 for Case Study 2). Although ergonomic improvements offer fewer body motions and better posture, they may call for longer action distances or idle time waiting for machinery to perform. When this occurs management must understand that making the ergonomic improvement is likely to payoff in the long run—just perhaps not in direct financial savings. Good ergonomics, which include reduced physical stress and less fatigue, improve the

Table 7. BasicMOST analysis for the proposed work situation integrating Improvement 5, which includes a 20° incline for the work surface.

Improvement 5: Inclining work-surface by 20° to impose safe working-posture in backboard nailing operations

	BasicMOST Analysis												Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Load 2 long boards	Sub-Operation Sequence	A_{10}	B_3	G_3	A_{10}	B_0	P_1	A_1					1	280	6	297
	Partial Frequency	1	1	1	1	1	1	1								
Load 2 short boards	Sub-Operation Sequence	A_{10}	B_3	G_3	A_{10}	B_0	P_1	A_0					1	270	6	286
	Partial Frequency	1	1	1	1	1	1	1								
Position long board to short board	Sub-Operation Sequence	A_6	B_0	G_3	A_1	B_0	P6	A_0					4	1,040	10	1,144
	Partial Frequency	1	1	2	2	1	2	1								
Assemble long board to short board with 3 nails using nail gun	Sub-Operation Sequence	A_3	B_0	G_1	A_1	B_0	P_3	F_1	A3	B_0	P_1	A_0	4	920	14	1,049
	Partial Frequency	1	1	1	3	3	3	3	1	1	1	1				
Load 2 rods	Sub-Operation Sequence	A_{10}	B_3	G_1	A_{10}	B_0	P_1	A_0					1	250	4	260
	Partial Frequency	1	1	1	1	1	1	1								
Position rod to long board	Sub-Operation Sequence	A_{10}	B_0	G_1	A3	B_0	P_3	A_0					4	680	5	714
	Partial Frequency	1	1	1	1	1	1	1								
Assemble rod to long board with one nail using nail gun	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_3	F_1	A_1	B_0	P_1	A_0	4	360	13	407
	Partial Frequency	1	1	1	1	1	1	1	1	1	1	1				
Change tool from nail gun to screwdriver	Sub-Operation Sequence	A_1	B_0	G_1	M_1	X_0	I_0	A_0					1	30	6	32
	Partial Frequency	1	1	1	1	1	1	1								
	Sub-Operation Sequence	A_0	B_0	G_0	A_1	B_0	P_1	A_0					1	20	6	21
	Partial Frequency	1	1	1	1	1	1	1								
	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_3	A_0					1	60	6	64
	Partial Frequency	1	1	1	1	1	1	1								
Position corner support	Sub-Operation Sequence	A_3	B_0	G_1	A3	B_0	P6	A_0					4	560	7	599
	Partial Frequency	1	1	2	1	1	1	1								

(continued)

Table 7. Continued.

Improvement 5: Inclining work-surface by 20° to impose safe working-posture in backboard nailing operations

	BasicMOST Analysis												Sub-Operation Frequency	Normal Operation Time [TMU]	Allowances [%]	Standard Operation Time [TMU]
Assemble corner support with 4 screws using power screwdriver	Sub-Operation Sequence	A_1	B_0	G1	A_1	B_0	P_3	F_3	A_1	B_0	P_1	A_0				
	Partial Frequency	2	1	2	4	4	4	4	2	1	2	1	4	1,440	13	1,627
Reonent Assembly	Sub-Operation Sequence	A_1	B_2	G_2	A_1	B_3	P_3	A_0								
	Partial Frequency	1	1	1	2	1	1	3					1	150	10	165
Change tool from screwdriver to nail gun	Sub-Operation Sequence	A_1	B_0	G_1	M_1	X_0	I_0	A_0								
	Partial Frequency	1	1	1	1	1	1	1					1	30	6	32
	Sub-Operation Sequence	A_0	B_0	G_0	A_1	B_0	P_1	A_0								
	Partial Frequency	1	1	1	1	1	1	1					1	20	6	21
	Sub-Operation Sequence	A_1	B_0	G_1	A_1	B_0	P_3	A_0								
	Partial Frequency	1	1	1	1	1	1	1					1	60	6	64
Load backboard	Sub-Operation Sequence	A_{10}	B3	G_3	A_{10}	B_0	P_3	A_3								
	Partial Frequency	1	1	1	1	1	1	1					1	290	7	310
Position backboard	Sub-Operation Sequence	A_3	B_0	G_3	A_1	B_0	P6	A_0								
	Partial Frequency	1	1	1	1	1	1	1					1	130	10	143

Assemble backboard to boards and rods with 54 nails usingnail gun	Sub-Operation Sequence	A_3	B_0	G_1	A_1	B_0	P_3	F_1	A_1	B_0	P_1	A_1				
	Partial Frequency	2	1	2	54	54	54	54	2	1	2	1	1	2,830	15	3,255
Reonent Assembly	Sub-Operation Sequence	A_1	B_2	G_2	A_1	B_3	P_3	A_0								
	Partial Frequency	1	1	1	2	1	1	1					1	150	10	165
Unload backboard	Sub-Operation Sequence	A_3	B_3	G_3	A_{16}	B3	P_3	A_{16}								
	Partial Frequency	1	1	1	1	1	1	1					1	470	10	517

Normal Cycle-Time [TMU]: 10,040

Allowance per Cycle: 11.3%

Standard Cycle-Time [TMU]: 11,171

Calculation of Savings and Break Even Quantity for considering improvement 1

Difference between existing and proposed Standard Cycle Times [TMU/Work-Cycle]	−524
Difference between existing and proposed Normal Cycle Times [TMU/Work-Cycle]	−520
Labour Costs per Hour	\$20
Operational Savings in 8 Hour Work-Day	−\$7.4
Savings in Allowances in 8 Hour Work-Day	−\$0.1
Total savings in 8 Hour Work-Day	**−\$7.5**
Invested Costs in improvement [\$]	\$25
BEQ (expressed in Work-Days):	–

Table 8. Table summarizing existing versus improved metrics for Improvements 1–3 for Case Study 1.

		Improvement		
Existing work situation		1 Lift for treatment cage	2 Lifts for raw material	3 Improve heights for divider boxes
Normal cycle time (minutes)	1.03	0.96	0.99	0.97
Allowances (minutes)	0.09	0.07	0.08	0.08
Standard cycle time (minutes)	1.12	1.03	1.07	1.05
Savings per work day ($)	–	$28.12	$14.99	$20.98
Investment ($)	–	$5000	$10 000	$100
Workdays to return investment	–	178	667	5
Manufacturing quantity to return investment	–	82 727	298 757	2 172

well-being of the company's employees, leading to a long term healthy, productive and efficient work relationship (Tichauer 1978). Good ergonomics also mean reduced injury and work-related disorders. Although these are difficult to measure, they can be accounted for in management's outlay on training new employees to replace veteran injured employees. Management will also be saving money which might be spent on legal fees to defend against lawsuits related to injury and on insurance premiums to prevent such. These can be calculated as the probability of injury (between 0 and 1) times the cost of injury (illness days, lawsuit expenses, etc.).

When the ergonomic factor is quantitatively expressed and derived through replicable measurement it can be managed, controlled by management and exploited for making decisions regarding workforce selection, taking into consideration resting times and most important, where to manufacture. Many work situations do not take into account physical stress in standard time calculations, as a result of poor ergonomics. This is often the case in countries that are not developed industrially and where the labour costs are low. For such cases, if we would like to see what happens when good ergonomics is put into the equation, we can assign different labour costs and check the breakeven quantities. It is likely that in such cases some ergonomic improvements will not return themselves within a reasonable planning horizon as the savings are lower per work cycle (when not considering improvements to allowances) and the investment in improvements stands. Just as labour costs may vary between countries, ergonomic attitude, policies, regulations and worker unions may influence setting allowances for standard cycle times. Since changes in allowance percentages are reflected in the standard cycle time, in order to distinguish between operational and ergonomic savings, an averaged allowance per cycle must be calculated and compared separately. For example, in Case Study 1 above, the standard cycle time is 1.12 minutes. Such a standard allows for 1.03 minutes of work and 0.09 minutes of rest (8.5% resting allowance). When Improvement 1 (a mechanical lift to

Table 9. Table summarizing existing versus improved metrics for Improvements 1–7 for Case Study 2.

		Improvement						
Existing work situation		1 Vertical screwdriver	2 Sling for screwdriver	3 Pronation in nailing	4 Vertical nail gun	5 Incline work surface by 20°	6 Sling for nail gun	7 Extra pneumatic installation
Normal cycle time (minutes)	5.71	5.72	5.71	5.71	5.71	6.02	5.71	5.58
Allowances (minutes)	0.68	0.65	0.66	0.67	0.64	0.68	0.63	0.67
Standard cycle time (minutes)	6.39	6.37	6.37	6.38	6.35	6.70	6.34	6.25
Savings per workday ($)	–	$0.37	$0.39	$0.14	$0.84	−$7.51	$1.23	$3.58
Investment ($)	–	$250	$150	$0	$ 250	$25	$150	$350
Workdays to return investment	–	669	389	0	299	Never	122	98
Manufacturing quantity to return investment	–	50 403	29 297	0	22 563	Never	9259	7504

accommodate the treatment cage) is inserted into the work cycle, a standard cycle time of 1.03 minutes is set, which allows 0.96 minutes of work and 0.07 minutes of rest (7.2% resting allowances). If resting is not accounted for, the savings will be calculated regardless of the difference in resting allowances and only operational improvements will be considered. In this example, the improved versus proposed normal work cycle time is 7% improved where the standard cycle time is 8.1% improved, meaning that improving work conditions results in further accountable improvements.

Although available CAD tools can meet ergonomic requirements for analysis and design, they still are not able to translate the improvement in posture into time metrics, therefore, the improvement is harder to compare, communicate to and thereby attract management. In this paper we translated ergonomic improvements into time and financial metrics. Note that the breakeven quantity can be alternatively calculated for the number of cycles or days to return the investment. The conversion is done using the cycle time of the job. When doing so, one must consider taking other times into account, such as loading and unloading the station or idle times. In such cases, the breakeven quantity will be calculated according to an expanded cycle time, which reflects the actual time to return the investment.

Without the proposed process, as laid out in this paper and the earlier one—viewing the work carried out 'live' (or the closest reflection of reality as possible), analysing the existing work situation as carried out by the worker, designing improvements according to the quantitative analysis ranked by acuity and costing improvements—correct decisions are hard to make. As shown in Elnekave and Gilad (2006), a standard time for the existing work situation can be set quite rapidly and remotely. Nevertheless, for formulating the proposed work situations, no formal techniques are available. We point to the need to validate how well the proposed work situations will reflect reality, as this was not studied. Although PMTS are known for their consistency and accuracy in prediction, many times it is up to the analyst to predict the correct work sequence, body motions and working postures (Delleman 1999). Accuracy in prediction is indeed needed for strategic planning in investment analysis of manufacturing times and costs.

5. Conclusion

Ergonomic models for analysis and redesign are time-consuming and, in many cases, questionable. The solution, frequently, can be sought intuitively, and quite quickly, by an experienced analyst. Still, the impact of implementing ergonomic improvements on operation time must be calculated using PMTS in order to facilitate managerial decisions regarding method improvement. Our approach does not compromise on this step and pushes towards making a quantitative analysis using simple computerized tools, reaching results quickly and remotely.

Our approach for making an ergonomic analysis includes combining work measurement calculations and ergonomic analyses for a complete work analysis (Laurig *et al.* 1985, Gilad 1995, Laring *et al.* 2002). This approach proposes quantifying the measured posture and then coupling operation times derived using formal work measurement techniques. Then the ergonomic factor can be expressed as a direct cause of the hidden trauma. The analyst can act upon that through projecting motion sequences of different solutions, calculating their costs and selecting the best one.

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