Policy analysis of the budget used in training program for reducing lower back pain among heavy equipment operators in the construction industry: System dynamics approach

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Abstract. Lower back pain (LBP), prevalence is high among the heavy equipment operators leading to high compensation cost in the construction industry. It is found that proper training program assists in reducing chances of having LBP. This study, therefore aims to examine different safety related budget available to support LBP related training program for different age group workers, utilizing system dynamics modeling approach. The simulation results show that at least 2.5% of the total budget must be allocated in the safety and health budget to reduce the chances of having LBP cases.

1. Introduction

The activities performed in the construction industry can lead to different health problems. It is found that the lower back pain (LBP) problem is the most common health problem in the construction industry [1]. The LBP prevalence in this industry is 50%, which is the highest among all industries [1, 2]. The heavy equipment operators (i.e. backhoe loader, bulldozer, compactor, crane, forklift, front end loader, skid loader, and tractor) are found having two times higher risk in developing LBP than non heavy equipment operators [3]. This is due to many risk factors, such as static work posture, whole-body vibration, poor climatic changes, and psychosocial factors such as job satisfaction [3].

The compensation cost due to LBP is high in the construction industry [4]. In United State, for example one third of the compensation cost paid is from LBP [4]. LBP is also the second most common reason for sick absence from work [4]. Webster and Snook [5] suggested that there should be a primary goal of reducing prolonged disability of workers as it constitutes high compensation expenditure. Yassierli[6] mentioned that sick leave can be reduced by 8% when the ergonomics programs are initiated. This shows that ergonomics programs may help to manage LBP and also other musculoskeletal cases. Lahiri [7] stated that training program is a low cost feasible first step towards the reduction of LBP that should be encouraged through policy and regulations.

This paper, therefore, aims to examine different safety and health budget used for training program utilizing a system dynamics (SD) modeling approach. Different scenarios were tested with different budget to examine the base scenario that a construction company can implement. It is expected that the outcome of study can assist the construction company in effectively plan for training program expenditure in the long term. The research steps of the model development are as shown in figure 1.
2. System Dynamics (SD) modelling
SD is a simulation method used for representing the structure of complex systems and understanding their behavior over time [8, 9]. SD is designed to use with large and complex systems [9]. In addition to that SD model offers obvious advantages than the other models [10]. It can be used in a variety of fields such as construction, education, economy, policy, environment, medicine, and health [9]. SD is well suited in chronic diseases prevention modeling too [10].

SD has been widely used in construction related research studies. Mohamed and Chinda [11] for example, utilizing SD to propose an index for assessing the maturity level of safety culture in the construction industry. Moreover Maryani et al. [12], developed a model using SD, which can generates occupational safety and health cost components that need to be controlled and improvements in the supply chain of subcontractors and supervisors to enhance the quality of workers in the construction industry. In addition to that Shin et al. [13] developed a SD model to examine the effectiveness of safety improvements in the construction industry.

In this study the SD model is used to develop a training program dynamic model for three different age groups. According to John Lant and Partners [14], young age (group A: 25-45 years), middle age (group B: 45-54 years), and senior (group C: more than 54 years) experience 48%, 54%, and 50% of chances having LBP respectively. The initial budget used for safety and health is averaged at 5% of the total construction project cost [15]. The training cost of the group A and group C is $100 per person. On the other hand the training cost of group B is $27higher than group A [7]. Workers should also be retrained every three year to ensure meet the safety and health standard [16].

3. The training program dynamic model development
The training program dynamic model consists of four sub models, namely 1) safety budget sector; 2) training sector; 3) retraining sector; and 4) chances of having LBP sector. The training program dynamic model is as shown in figure 2.

3.1. Safety budget sector
Pellicer et al. [15] illustrates that the safety and health costs in a construction project is approximately 5% of the total budget. In this study, the safety and health budget is initially set at 5% of the total budget with an increasing rate of 2% per year (see eq.1). This budget is used for different purposes such as implementation of safety policies, site safety inspection, education and training, and provision of personal protective equipments [17].The training budget is therefore considered as 10% of the safety budget.
Figure 2. Training program dynamic model.
Budget for safety = 
\[ ((\text{Total budget of the construction project} \times \text{Budget Increasing rate}^{(\text{Year}+1)})) \times 0.05 \]  
(1)

3.2. Training sector
Training sector is divided into three sub sectors, namely i) A group training sector, ii) B group training sector, and iii) C group training sector.

3.2.1. C group training sub sector
Total C operators are as shown in equation 2, represent total C group workers. This amount is changed based on hiring and resigning rate. This group of workers has the priority to receive the training, as they are in old ages, and might be less fit than those in younger ages. The initial B operators are assigned to the without training sector at the beginning. The numbers of trained workers in this group are based on budget allocated with training cost per person (see eq.3). If the budget is not enough to train all the operators, the remaining operators are considered as the "operators without training" (see eq.4). Leftover budget is used to train the operators in the group B and group A respectively (see eq.5).

\[ \text{Total C operators} = \text{ROUND}((\text{C initial operators} \times \text{Net Hiring and Turnover C}^{(\text{Year})})-0.5) \]  
(2)

\[ \text{Train rate C} = \text{IF} (\text{Required budget C}>\text{Budget for training of heavy equipment operators}) \text{ THEN ROUND}((\text{Budget for training of heavy equipment operators}/\text{C Training cost per person})-0.5) \text{ ELSE } (\text{Without Train C}+\text{New C operators}) \]  
(3)

\[ \text{Without train C rate} = \text{IF}((\text{Without Train C}+\text{New C operators})<\text{Train rate C} \text{ OR } (\text{Without Train C}+\text{New C operators})=\text{Train rate C}) \text{ THEN } 0 \text{ ELSE } ((\text{New C operators})-\text{Train rate C}) \]  
(4)

\[ \text{Leftover of C training} = \text{Budget for training of heavy equipment operators}-(\text{C Training cost per person} \times \text{Train rate C}) \]  
(5)

3.2.2. B group training sub sector
Total B operators are as shown in equation 6, represents total B group workers. This amount is also changed based on hiring and resigning rate. The numbers of trained workers in this group are based on the leftover budget of after C operators training and allocated with training cost per person (see eq.7). If the budget is not enough to train all the operators, the remaining operators are considered as the "operators without training" (see eq.8). Leftover budget is used to train the operators in the A group (see eq.9).

\[ \text{Total B operators} = \text{ROUND}((\text{B initial operators} \times \text{Net Hieing and turnover B}^{(\text{Year})})-0.5) \]  
(6)

\[ \text{Train rate B = IF} (\text{Required budget B}>\text{Leftover of C training}) \text{ THEN ROUND}((\text{Leftover of C training}/\text{B training cost per person})-0.5) \text{ ELSE } (\text{Without Train B}+\text{New B operators}) \]  
(7)

\[ \text{Without train B rate} = \text{IF}((\text{Without Train B}+\text{New B operators})<\text{Train rate B} \text{ OR } (\text{Without Train B}+\text{New B operators})=\text{Train rate B}) \text{ THEN } 0 \text{ ELSE } ((\text{New B operators})-\text{Train rate B}) \]  
(8)

\[ \text{Leftover of B training} = \text{Leftover of C training}-(\text{Train rate B} \times \text{B training cost per person}) \]  
(9)

3.2.3. A group training sub sector
Total A operators are as shown in equation 10, represents total A group workers. This amount is also changed based on hiring and resigning rate similar to the B group, and A group. The numbers of trained workers in this group are based on the leftover budget after training B operators and allocated with training cost per person (see eq.11). If the budget is not enough to train all the operators, the
remaining operators are considered as the “operators without training” (see eq.12). Leftover budget is used to retrain all the operators (see eq.13).

\[
\text{Total A operators} = \text{ROUND}((\text{A}_{\text{initial operators}} \times \text{Net Hiring and turnover}_A^\text{Year}) - 0.5) \tag{10}
\]

\[
\text{Train rate A} = \text{IF} (\text{Required budget}_A > \text{Leftover of B training}) \text{THEN} \text{ROUND}((\text{Leftover of B training} / \text{A Training cost per person}) - 0.5) \text{ELSE} \text{Without Train A} + \text{New A operators} \tag{11}
\]

\[
\text{Without train A rate} = \text{IF}((\text{Without Train A} + \text{New A operators}) < \text{Train rate A} \text{OR} (\text{Without Train A} + \text{New A operators}) = \text{Train rate A}) \text{THEN} 0 \text{ELSE} (\text{New A operators} - \text{Train rate A}) \tag{12}
\]

\[
\text{Leftover of training operators} = \text{Leftover of B training} - (\text{Train rate A} \times \text{A Training cost per person}) \tag{13}
\]

3.3. Retraining sector

After three years, the trained workers must be retrained to maintain standard [16] (see eq.14). Due to the limited budget, however, not all trained workers are retrained. The number of retrained workers is as shown in the equation 15, are then calculated based on the leftover budget with an average training cost of 109$ per person.

\[
\text{Total trained} = \text{Trained A} + \text{Trained B} + \text{Trained C} \tag{14}
\]

\[
\text{Retrain rate} = \text{IF}((\text{Need retrain} \times \text{Average training cost per person}) > \text{Leftover of training operators}) \text{THEN} \text{ROUND}((\text{Leftover of training operators} / \text{Average training cost per person}) - 0.5) \text{ELSE} \text{Need retrain} \tag{15}
\]

3.4. Chances of having LBP sector

Total chances of having LBP is calculated based on trained and without train operators in all three age groups (see eq.16-18).

\[
\text{Ratio of without training} = (\text{Without Train A} + \text{Without Train B} + \text{Without Train C}) / \text{Total operators} \tag{16}
\]

\[
\text{Ratio of with training} = (\text{Trained A} + \text{Trained B} + \text{Trained C}) / \text{Total operators} \tag{17}
\]

\[
\text{Total chances of having LBP} = ((\text{Ratio of without training} \times \text{Without train chances of having LBP}) + (\text{Ratio of with training} \times \text{with train chances of having LBP})) \tag{18}
\]

4. Results simulation

Prevalence of the LBP among the heavy equipment operators are 63% [18]. Therefore, at the beginning of simulation the model the average chance of having LBP among three groups of workers is considered as 63% [18]. With training the chance of having LBP reduces and reach minimum point of 48% (see figure 3). This is consistent with Lahiri et al. [7], reduces chances of having LBP after receiving training, reduced by 15%. This is due to the workers have knowledge about correct posture of working, and how to operate the machines safely comes from training program.

Figure 4 show that, different age groups experience different chances of having LBP. For C and B group the chance reduce from 63% to 48% within one year. This might be because numbers of workers in these two groups are small. On the other hand A group which contribute the most population in the construction operation experience 4 years of reducing LBP from maximum to minimum.
5. Policy testing of the training program for heavy equipment operators

In real practices, budget allocation to safety and health might not reach 5% of the total budget. Different safety and health budget are then simulated to investigate minimum budget required to achieve the lowest chance of having LBP. Table 1 and Figure 5 show that, with 1% of total budget allocated for safety and health, cannot be reduced the chances of having LBP by 15%, which is the reduction of LBP chances by implementing training program [7].

Table 1. Variation of chances of having LBP for different percentage of safety budget

| Year | 1    | 1.5  | 2    | 2.5  | 3    | 3.5  | 4    | 4.5  | 5    |
|------|------|------|------|------|------|------|------|------|------|
| 1    | 63.00| 63.00| 63.00| 63.00| 63.00| 63.00| 63.00| 63.00| 63.00|
| 2    | 62.21| 61.84| 61.44| 61.07| 60.68| 60.21| 59.72| 59.23| 58.74|
| 3    | 61.53| 60.82| 59.83| 58.88| 57.94| 57.01| 56.06| 55.13| 54.18|
| 4    | 60.93| 59.57| 58.11| 56.73| 55.36| 53.99| 52.60| 51.23| 49.84|
| 5    | 60.17| 58.38| 56.47| 54.68| 52.89| 51.10| 49.29| 48.00| 48.00|
| 6    | 59.46| 57.27| 54.94| 52.76| 50.58| 48.40| 48.00| 48.00| 48.00|
| 7    | 58.77| 56.21| 53.48| 50.93| 48.36| 48.00| 48.00| 48.00| 48.00|
| 8    | 58.13| 55.21| 52.09| 49.19| 48.00| 48.00| 48.00| 48.00| 48.00|
| 9    | 57.54| 54.27| 50.48| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 10   | 57.00| 53.37| 49.55| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 11   | 56.53| 52.52| 48.39| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 12   | 56.11| 51.74| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 13   | 55.78| 51.01| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 14   | 55.50| 50.36| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 15   | 55.27| 49.79| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 16   | 55.08| 49.29| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 17   | 54.98| 48.94| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 18   | 54.91| 48.69| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 19   | 54.90| 48.56| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|
| 20   | 54.91| 48.45| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00| 48.00|

Figure 3. Chances of having LBP for 5% of total budget.

Figure 4. Chances of having LBP for different age groups.
Minimum budget required to achieve the lowest chances of having LBP is 2% and it will take 12 years. On the other hand if the company needs to achieve the lowest chance of 48% in 10 years minimum of 2.5% of total budget should be allocated for safety related activities (see Table 1). With the budget of 5% the company can achieve the lowest chance in only half of the time (which is five years).

6. Conclusion
LBP problems are considered as the most common health problem in the construction industry among the heavy equipment operators. It causes to lose of money due to compensation cost and sick leaves. Therefore the current study model the implementation of training program as training program considered as the cost effective intervention for LBP in the construction industry. Training program dynamic model is developed using SD modeling. The model is simulated with different safety and health budget to find the lowest percentage of construction cost to reach the minimum chances of having LBP. The simulation results can be used as a guideline for implement training program for heavy equipment operators in the construction industry.

Simulation results shows, at least 2.5% of total budget must be allocated for health and safety related activities to reach the minimum chances of having LBP by implementing training program in 10 years. With the budget of 5% of total cost, the company can achieve the lowest chance in five years. It is expected that the construction companies will use this SD model to effectively plan and impalement training program in the construction industry. Moreover the implemented values in this model, such as number of operators, increasing rate of construction budget, increasing rate of training budget per operator, and hiring and turnover rate can be changed by Construction Company.

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