

Ergonomic Interventions for Designing the Workstation of a Manual and Highly Repetitive Lifting Task in a Paint Industry

Afifa Sumaya, Aquib Irteza Reshad, Nowsheen Sharmili, Muniom Shahriar

Department of Industrial and Production Engineering
Bangladesh University of Engineering and Technology
Dhaka, 1000, Bangladesh

eyantitushi@gmail.com, reshad10810@gmail.com, n7sharmili@gmail.com,

mridulthegreat69@gmail.com

Abstract

The filling station plays a substantial role in the paint manufacturing industry where manual activities are omnipresent. An ergonomic study was conducted at the filling station of a renowned paint factory in Bangladesh since this factory includes numerous manual activities. A highly repetitive manual lifting job was selected among those tasks for measuring the Lifting Index (LI) as a mean of quantifying the risk since that continuous lifting job looked susceptible to musculoskeletal disorders and lower back pain. The VLI (variable lifting index) method which takes biomechanical, physiological, and psychophysical into account was used for determining the LI. The value of the LI for the existing layout was found to be greater than 1, bearing the significance that this task can be the impetus to back pain in the future. To resolve the problem, an improved optimized ergonomic design was suggested that could lower the LI to a safe level ($LI < 1$). The implementation of the improvised design will lessen the risk of lower back pain for the workers performing that task.

Keywords

Ergonomics, Work-station design, High-frequency lifting, Musculoskeletal disorders, Risk assessment

1. Introduction & Literature Review

Different design components of the workstation along with the imposed precision placement condition constrains the movement of a worker during the performance of the highly repetitive manual lifting task in palletization process. The requirements of lifting a finished good from the workstation and subsequently placing it manually within a designated area have substantial impacts on upper body kinematics and result in a greater trunk muscle activation levels, trunk angular displacements, and moments about the lumbar spine and lumbar spine compression and shear forces Devis et al. (2002); Beach et al. (2006). In industry, increased cumulative lumbar spine load can exceed the tolerance level of the intervertebral joints (Waters et al. 1993) causing low back pain (Kumar et al. 1990; Norman et al. 1998).

Comprehensive literature reviews have provided strong evidence indicating the relation between LBP/MSDs and manual lifting operations in industrial works Keyserling et al. (2000), Kuizer et al. (2014). The intensity and frequency of lifting were significantly associated with annual incidence of LBP and potentially lead to an increment of annual incidences of LBP by 4.3% and 3.5%, respectively (Coenen et al. 2014). There were 2.8 million nonfatal workplace injuries and illnesses recorded by private industry employers in 2018 according to the U.S. Bureau of Labor Statistics reports. With approximately \$1 out of every \$3 in worker's compensation costs attributed to MSDs (The Washington State Department of Labor and Industries), this provides an opportunity for significant cost reductions. In developing countries such as Bangladesh, the occupational health and ergonomic hazards and injuries are perceived less attention in particular, the MSDs and LBP issues. The working situation in the lifting task is more physically demanding and stressful than the pulling task. Approximately two-thirds of over-exertion injury involves lifting loads, and about 20% involved pushing or pulling loads (National Research Council, 2001; Nelson et al. 2009; Basahel, et al. 2015).

The frequency and intensity of lifting are the dominant variables that affect the possible magnitude of loads on the lower back. Exposure-response relationship and meta-analysis demonstrated that the ideal lifting limit is reduced substantially when the lifting situation consists of non-ideal situation like large horizontal or vertical load distances,

acceleration of the upper body and upper extremities, asymmetry, high frequency or inappropriate coupling of the load (Burdorf et al. 2010; Coenen et al. 2014). This is in line with NIOSH (Waters et al. 1993). Lifting strategies also have some impacts on the distribution of internal forces on the spine. But, recent studies shows that the experienced workers can keep good balance and ensure reduced knee flexion torso movement stability Lee and Nussbaum et al. (2013); Plamondon et al. (2014). Therefore, an ergonomic intervention to reduce risk of LBP or MSDs should pre-eminently concern about major factors such as the horizontal distance, frequency and height of the load rather than focusing on workers' techniques.

Assessing the interaction between worker and workplace and subsequently changing the working situation considering all ergonomic factors and optimizing design parameter can lead to an improving lifting situation. The station from which the worker lifts a finished good and dispatches it on a pallet has a major impact on spine loading thus associates with low back pain (Davis et al. 1998; Plamondon et al. 2014). The horizontal distance between the load and worker is also related with the external moment at L5/S1. Previous research efforts showed a significant reduction of risk factors incorporating ergonomic considerations by ensuring low back loading (Vander et al. 2004; Kuijner et al. 2014). In this paper, a mathematical model is demonstrated and applied to analyze the ergonomics risk factors associated with the manual lifting operation of a semi-automated paint filling station. Various design options for a workstation can be assessed and evaluated from an ergonomics perspective to ensure the safety of the worker. Different lifting index from different design options can then be compared for an optimum result. More modifications of an existing design can also be done aiming to reduce the lifting index which will also promote a safer working environment.

In this paper, Section 2 introduces several approaches and best selected approach to design the work station. A real-life case study regarding the lifting task problem is delineated in section 3 with a modified design and comparison between the designs. Section 4 discussed about the results of the modified ergonomic approach following conclusion in section 5.

1.1 Objectives

This study has examined and identified the components of work tasks and workstations that may have an impact on the elected movement of workers and contribute to LBP during the performance of the repetitive high-frequency manual lifting task in the palletization process. A real-life case study in a paint manufacturing industry is illustrated in this paper where different parameters of the workstation, as well as the intensity and frequency of the lifting task, are evaluated as a component of a system and risk factors associated with a design are also quantified which can lead to an improved mitigation strategy.

2. The proposed methodology

2.1 Multiple approach to workstation design

Nowadays, different tools of ergonomics (depicted in Table 1) are being applied widely to design a safe working environment for the workers. These tools provide different systematic approaches to find out potential risk factors associated with repetitive works, long-term static posture, heavy or repetitive lifting, exposure to excessive vibration (Simon et al. 1991). The risk level can also be evaluated with proper calculations for an existing system and mitigation strategies can be developed.

RULA (Rapid Upper Limb Assessment) is a survey-based ergonomic tool that examines the upper extremities to figure out risk factors affiliate with musculoskeletal disorders (MSDs). Hedge et al. (2000) have presented this tool in the year 1993. It analyzes static postures of the workers by using the RULA employee assessment worksheet and marks down the level of risk. After the introduction, it has been used by the experts at different workplaces. Singh et al. (2012) have worked with the working posture of dental students during the teeth operation in two seating condition, it has assessed the MSDs of the workers in small scale forging industry with this tool. Davis et al. (2002) analyzed the risks in the packaging industry by using the RULA method and Digital Human Modelling (DHM). Hignett et al. (2000) have introduced another survey-based tool Rapid Entire Body Assessment (REBA) in the year 2000. It evaluates the risk by assessing the overall body posture of a worker using a worksheet. Both the RULA & REBA are a survey-based tool but the types of posture and works to be assessed are different for this. REBA results in better to evaluate the professions which include dynamic and unpredictable postures like health care and service industries. RULA is more suitable to measure static postures with repetition of the same action as the production line work profession (Tee et al. 2017).

Table 1. Limitations of Ergonomic Tools

Tool	Limitations
RULA	<ul style="list-style-type: none"> • At a time, analysis can be done on only one side of the body • Thumb and other fingers cannot be analyzed • Scoring is too general to differentiate between levels
REBA	<ul style="list-style-type: none"> • Biomechanical risk factors are not integrated • Analysis cannot be done in-depth since the method is too simple
LBA	<ul style="list-style-type: none"> • Analysis of virtual body rather than actual human • The only biomechanical factor is considered
OWAS	<ul style="list-style-type: none"> • No analysis on wrist and elbow • The left and the right side is not separated • Duration of posture is out of consideration

Low Back analysis is another tool to calculate the strength of a virtual manikin's spine where posture and loading on the virtual human model are given as input. NIOSH standard is maintained in this tool and also Raschke et al. (1994) studies on this field are also followed when the actions related to a task are evaluated in real-time. Not only detailed information on cut strengths and compression on the lumbar discs (L4 and L5) but also sagittal, axial, and lateral moments that are created on the L5 and L5 discs can be pulled out by this LBA tool. Furthermore, the details about trunk muscle activity level to balance those moments created in spines can be obtained.

Another simple tool for ergonomic analysis is Ovako Working Posture Analysis System or OWAS. OWAS was first introduced in 1973 by Ovako Oy to analyze the workload in the overhauling of iron smelting ovens in a steel industry company situated in Finland (Karhu et al. 1977). For coding and analysis of the OWAS, portable computer program has also been developed (Kivi 1991). OWAS shows the comforts related to a work posture and identifies the urgency of corrective actions needed for that posture. In OWAS the body is divided into four parts, Trunk, Arm, Lower Body, and Neck. Each section of the body is observed during a posture. There are different levels based on the position of that part and also the percentage of time spent in that position. The tasks are classified into four classes:

- “no harmful effect” which means no corrective actions are needed.
- “a limited harmful effect” meaning corrective measures are needed and can be introduced in the next regular review,
- “recognized the harmful effect on health” which tells to take actions as soon as possible,
- “highly harmful health effects” which means emergency measures are needed at this moment.

Lastly, NIOSH or National Institute for Occupational Safety and Health introduced an equation that is commonly known as NIOSH lifting equation. This equation can give a recommended weight limit for a specific lifting task. Three main factors are taken into consideration for this approach which are,

- Biomechanical: Where the body is seen as a system of joints and links where load analysis is done using the principles of physics.
- Physiological: This factor is concerned with the energy consumption of the body and oxygen consumed during a task which can indicate the stress associated with a task.
- Psychophysical: Maximum weight load that is acceptable for men and women is incorporated in this factor as capacity is decreased when a lifting task is done for a longer period.

The main purpose of this equation is to lower back pain and disability which can be resulted from a lifting task.

2.2 Selected Approach

Among the tools that are mentioned above, NIOSH equations were used for this paper since NIOSH has some advantages over other tools. Of course, there are some limitations of the NIOSH equation also but the factors that are taken into considerations in this equation are way better than other tools depicted in Table 1. Factors like the grip of the product, asymmetric position of the body duration of a task are present in the NIOSH equation which cannot be found in other tools. Work consisting of multiple lifting tasks can also be assessed by the NIOSH lifting equation. Most importantly, NIOSH can be applied where a variable lifting task is present which is similar to the case in this paper.

The flow chart of the NIOSH approach is presented in Figure 1. The initial step was to select a workstation where there was a possibility of lower back pain. Workstations associated with manual handling and lifting of heavy objects are ideal for this kind of assessment.

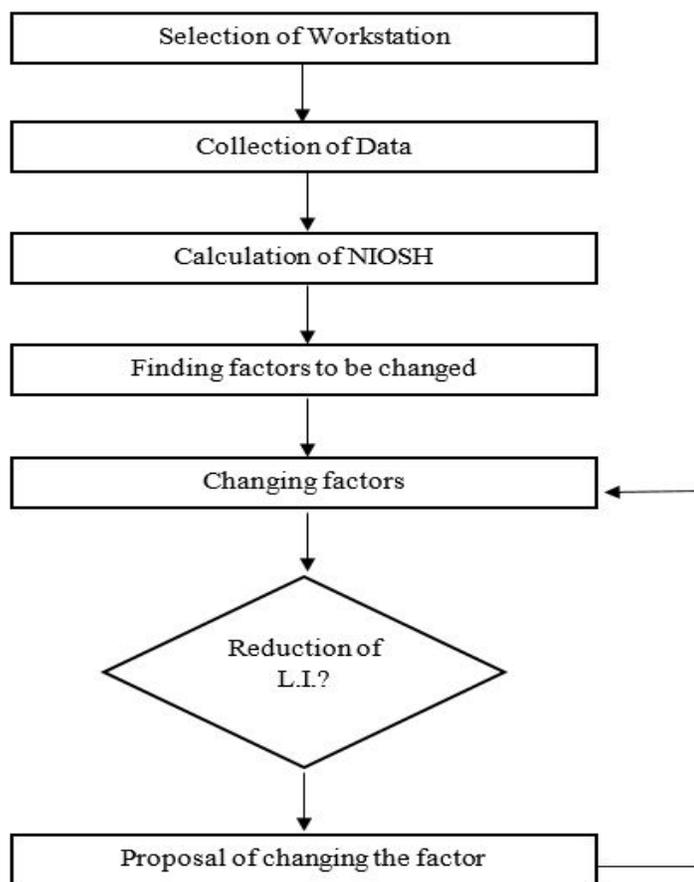


Figure 1. Flow chart depicting the procedures of the selected approach

The second challenge was to collect the data that was needed for the calculation of the lifting index. The horizontal distance, vertical distance, asymmetric position of the body, frequency, duration of the work, grip of the object all were noted down. The data that were collected for the calculation is:

- L: Weight of the object.
- H: Horizontal distance between the midpoint of the ankles and hands.
- V: Vertical distance between hands and floor.
- D: Absolute vertical distance between the origin and the destination.
- A: Angle between the mid-sagittal plane and the object.
- F: Frequency (lifts/minute) of the lifting task.

- C: Grip of the object.

The next step was the quantitative calculation. Since all the tasks are not the same, the traditional approach could not be used rather than an advanced approach to calculate the VLI was followed. Using that VLI equation the lifting index was calculated. The procedure and equations are given in the quantitative calculation section. For assessing different kinds of lifting tasks together, VLI method is needed. The VLI method developed by Waters et al. (2016), was used for this paper. The basic VLI method was introduced by Waters et al. (2009), where the maximum nine FILI categories could be used. But dividing the range into six categories can give the most efficient result (Waters et al. 2016). Therefore, our tasks will be divided into six categories. The sampling approach was used to obtain the data required to apply the VLI method. The steps for this approach are as follows (Waters et al. 2009):

- Data needed to calculate FILI and STLI are collected.
- The FILI range should be defined and divided into six categories with equal range.
- Each lift is assigned to the appropriate category and the average frequency is also calculated for each category. The categories of LI are rearranged and numbered according to the physical stress which begins with the category with the highest STLI (the LI of an individual task) and so on.

Using the CLI defined by Waters et al. (2009), VLI is calculated by following the equations below.

$$VLI = STLI_1 + \sum \Delta LI \quad (1)$$

$$\begin{aligned} \sum \Delta LI = & (FILI_2 \left(\frac{1}{FM_{1,2}} - \frac{1}{FM_1} \right) + FILI_3 \left(\frac{1}{FM_{1,2,3}} - \frac{1}{FM_{1,2}} \right) + FILI_4 \left(\frac{1}{FM_{1,2,3,4}} - \frac{1}{FM_{1,2,3}} \right) \\ & + FILI_n \left(\frac{1}{FM_{1,2,\dots,n}} - \frac{1}{FM_{1,2,\dots,n-1}} \right) \end{aligned} \quad (2)$$

Where, subscript numbers mean the LI category number. FM values are achieved from the Applications Manual for the Revised NIOSH Lifting Equation (Waters et al. 2009).

The selection of factors to change for improvement is the most critical among all the steps. The methodology of this paper is based on improving an existing configuration of the workstation. The approach is called the Initial Solution. The initial solution can be obtained from a simulation of the current structure of the workstation or the existing real workstation. There are some criteria for the selection of factors or design parameters. The criteria are,

- Controllable (both physically and economically)
- Continuous in nature
- Influential on the measures of interest

There are no hard and fast rules to select the factors. The selection is based on the experience and intuition only. If the lifting index is found to be greater than 1 after the calculation, it can be reduced by changing any design parameter. This is a trial and error procedure where one factor is changed at once and then the change in the lifting is calculated. If the index is less than one for all the positions, then the modified design could be proposed to be done by the authority since it would lower the probability of low back pain of the worker who works in that workstation.

3. An illustrative real life case study

3.1 Problem Description

The systematic ergonomics approach to design a work station where lifting operation is done manually on a continuous basis demonstrated above was applied to evaluate and design a filling station of a paint industry. Faber et al. (2009) implied that different results can be achieved from a laboratory simulated lifting task as opposed to a real industrial workplace. This study illustrates how the mathematical model can be applied to prevent musculoskeletal injuries in a real workplace situation. The existing design of a filling station in a paint industry's plant was assessed. A container is filled in with paint automatically and placed on a pallet manually. In the process, the worker has to lift the container from the receiving end of the conveyor and has to put this on the pallet. The working posture with other necessary information were collected through direct observation. A batch of 183 containers was observed. The vertical and horizontal distance of every container placed on the pallet was recorded at its origin (the receiving end of the conveyor)

and its destination (pallet). The frequency of this task was also recorded. Moreover, the coupling situation was observed to find out whether it is firm enough for lifting. The dimensions are given in the figures below:

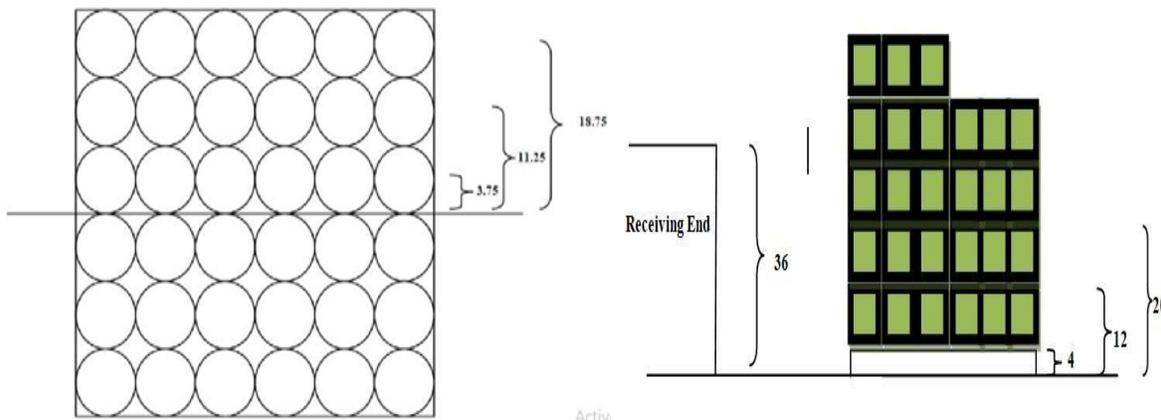


Figure 2. Top and Side view of the pallet

The filling workstation was selected not just because of the height or horizontal distance but also for the repetitive nature of the task. The worker had to fill a pallet of 183 can of paint in just 5 or 6 minutes. In consequence, the frequency of the task was very high than other tasks that were present in that paint factory. Moreover, the positions of the cans to be placed were much diverse and need precision placement on the pallet that some postures were too unusual. So, this makes the lifting task more prone to lower back injury. The environmental factors like temperature or humidity are not considered here because the plant has a good ventilation system and there are enough fans for workers' comfort. One thing to be noted here that the worker sometimes moves during the lifting task but that can be neglected as the movement is very much limited.

3.2 Quantitative Analysis

The horizontal and vertical distances were computed for data collection shown in Figure 2. The frequency was calculated using a stopwatch and there was no angle between the mid-sagittal plane and the object. The coupling was in ideal condition as there was a handle for holding those cans.

Table 2. Calculation of VLI (Origin)

Data Category	Number of Tasks in Each Category	Percentage of Tasks	Representative FILI Within Category	Frequency (lifts/min)	FM	ΔFILI	VLI
0.15	63	34.43	0.18	1.97	0.29	0.25	0.9071
0.20	36	19.67	0.22	1.13	0.48	0.09	
0.24	24	13.11	0.25	0.75	0.59	0.03	
0.28	10	5.46	0.29	0.31	0.64	0.03	
0.32	26	14.21	0.34	0.81	0.69	0.02	
0.36	24	13.11	0.42	0.75	0.72		

The calculation table of both origin and destination are shown in Table 2 and Table 3. There were six categories for origin but only five for the destination as the destination had fewer variations.

Table 3. Calculation of VLI (Destination)

Data Category	Number of Tasks in Each Category	Percentage of Tasks	Representative FILI Within Category	Frequency (lifts/min)	FM	ΔFILI	VLI
0.29	34.00	18.58	0.29	1.06	0.29	0.24	1.06
0.31	41.00	22.40	0.31	1.28	0.38	0.21	
0.33	36.00	19.67	0.33	1.13	0.51	0.11	
0.34	36.00	19.67	0.34	1.13	0.62	0.09	
0.35	36.00	19.67	0.35	1.13	0.74		

As the computed lifting index for the destination was more than 1, there was a high possibility of lower back pain for the worker and therefore, needed to be decreased by changing any of the factors. Since the weight of the can could not be changed for a specified can, the height of the receiving end was made 2 inches less than the previous one that gave a better solution. The calculation is shown in Table 4 and Table 5 after this update.

Table 4. Calculation of VLI after changing the Height (Origin)

Data Category	Number of Tasks in Each Category	Percentage of Tasks	Representative FILI Within Category	Frequency (lifts/min)	FM	ΔFILI	VLI
0.110	24.000 0	13.1148	0.110	0.120 0	0.75 02	0.290 0	0.8709
0.160	63.000 0	34.4262	0.160	0.190 0	1.96 92	0.360 0	
0.210	46.000 0	25.1366	0.210	0.240 0	1.43 78	0.550 0	
0.260	0.0000	0.0000	0.260	0.000 0	0.00 00	0.000 0	
0.310	26.000 0	14.2077	0.310	0.310 0	0.81 27	0.710 0	

Table 5. Calculation of VLI after changing the Height (Destination)

Data Category	Number of Tasks in Each Category	Percentage of Tasks	Representative FILI Within Category	Frequency (lifts/min)	FM	ΔFILI	VLI
0.21	34.00	18.58	0.21	1.06	0.29	0.17	0.94
0.30	41.00	22.40	0.30	1.28	0.38	0.20	
0.31	36.00	19.67	0.31	1.13	0.51	0.07	
0.33	36.00	19.67	0.33	1.13	0.62	0.09	
0.34	36.00	19.67	0.34	1.13	0.74		

3.3 Results

For the existing layout, the Lifting Index for destination and origin was calculated respectively, 1.06 and .9071. So, it was quite safe for the origin but the weight was greater than the recommended limit for the destination. A modified design considering the risk factors associated with this task is recommended in Figure 3. After changing one design parameter (height) of the workstation (origin) and the pallet (destination), the lifting index of both destination and origin was decreased.

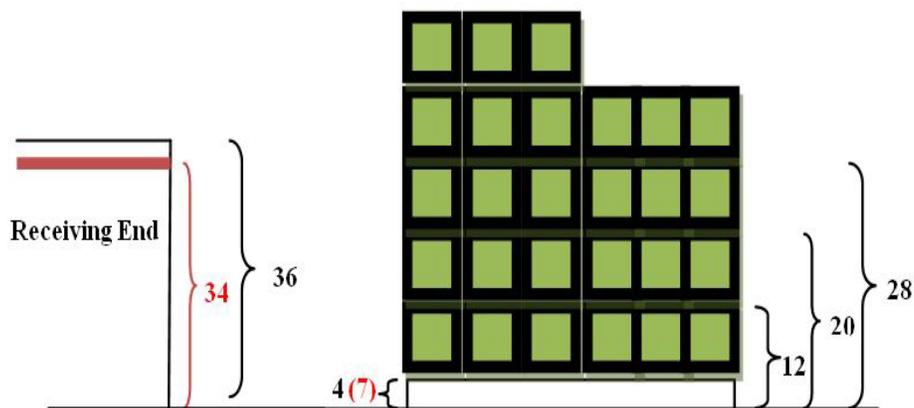


Figure 3. Proposed Design

Both lifting indexes were less than 1 which represented a lower possibility of lower back pain for the workers illustrated in Figure 4. Therefore, the suggestions to the authority were to lift the pallet by more than three inches and lower the receiving end by only two inches for a better ergonomic environment to increase productivity.

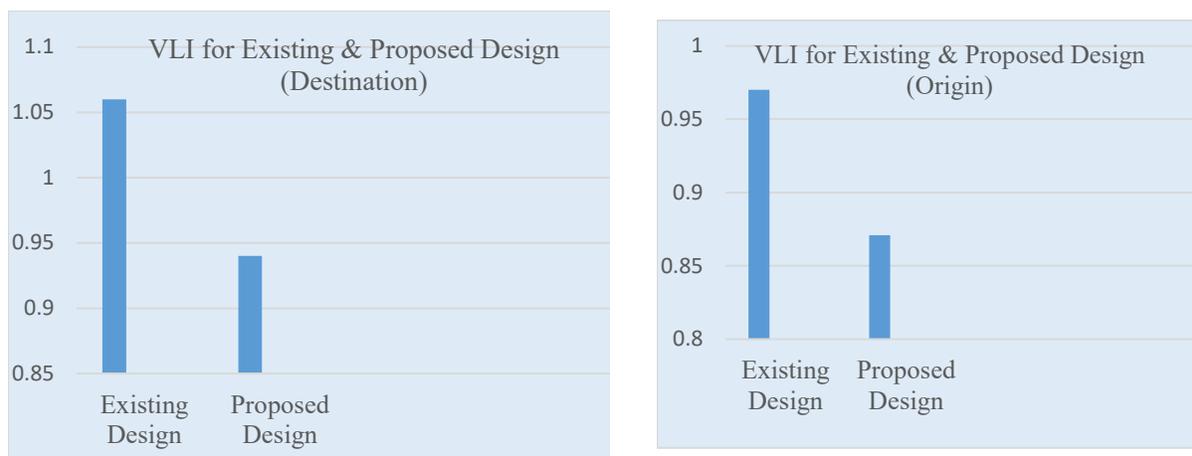


Figure 4. VLI for existing & proposed design (Destination & Origin)

4. Discussion

Ergonomic assessment is substantial for the workers of an industry who are indulged in manual lifting task. It increases the possibility of lower back pain which is prominent among the people doing lifting tasks frequently. The study applied a mathematical model to identify any lifting task which can be detrimental to health, assess the task and thereafter design the task for a safer movement of products. Increasing the destination height appeared to be the most effective way to reduce the risk index and low back loading. The achieved reduction in exposure to lifting risk is quantified here in order to provide insight of the effectiveness of the ergonomic intervention. This will not only increase productivity but also decrease the possibility of lower back pain of workers in the long run.

However, the working posture of the worker is not considered or assessed in this paper. A more sophisticated method can be developed by incorporating posture analysis using other ergonomic tools like RULA (Rapid upper limb assessment), OWAS (Ovako working posture analysis system) with this method to calculate PEI (Performance evaluation index) (Muslim et al. 2011). This index considers all the approaches to optimize the design of a work station which will maximize the safety and workers' comfort along with minimizing the risk for any musculoskeletal injuries (MSIs) during manual operation. Future research efforts can aim to develop a model that will combine all these factors and generate a risk index for any design of a workstation.

6. Conclusion

In conclusion, it is found that ergonomic interventions for designing the workstation did reduce the risks associated with a manual and highly repetitive lifting task. The result shows that existing design could contribute to low back pain or musculoskeletal injuries in the workplace. The recommended design proposed a simple modification of the design parameters and mitigated the overall risks. Therefore, to obtain accurate estimates of the effect of ergonomic interventions on design, it is essential to closely simulate the work station and workplace situation of interest in a virtual environment or test experiment, performed by workers who have experience with the particular lifting task. Moreover, the design parameters can be changed simultaneously to investigate the effects and optimize the overall lifting situation by determining the optimum design parameters for alleviating the risks for LBP or MSDs.

References

- Basahel, A.M., 2015. Investigation of work-related Musculoskeletal Disorders (MSDs) in warehouse workers in Saudi Arabia. *Procedia Manufacturing*, 3, pp.4643-4649.

- Beach, T.A., Coke, S.K. and Callaghan, J.P., 2006. Upper body kinematic and low-back kinetic responses to precision placement challenges and cognitive distractions during repetitive lifting. *International Journal of Industrial Ergonomics*, 36(7), pp.637-650.
- Burdorf, A., 2010. The role of assessment of biomechanical exposure at the workplace in the prevention of musculoskeletal disorders. *Scandinavian journal of work, environment & health*, 36(1), p.1.
- Coenen, P., Gouttebauge, V., van der Burght, A.S., van Dieën, J.H., Frings-Dresen, M.H., van der Beek, A.J. and Burdorf, A., 2014. The effect of lifting during work on low back pain: a health impact assessment based on a meta-analysis. *Occupational and environmental medicine*, 71(12), pp.871-877.
- Davis, K.G., Marras, W.S., Heaney, C.A., Waters, T.R. and Gupta, P., 2002. The impact of mental processing and pacing on spine loading: 2002 Volvo Award in biomechanics. *Spine*, 27(23), pp.2645-2653.
- Faber, G.S., Kingma, I., Kuijer, P.P.F.M., Van der Molen, H.F., Hoozemans, M.J.M., Frings-Dresen, M.H.W. and Van Dieen, J.H., 2009. Working height, block mass and one-vs. two-handed block handling: the contribution to low back and shoulder loading during masonry work. *Ergonomics*, 52(9), pp.1104-1118.
- Hedge, A., 2000. RULA employee assessment worksheet. *Cornell University*.
- Hignett, S. and McAtamney, L., 2000. Rapid entire body assessment (REBA). *Applied ergonomics*, 31(2), pp.201-205.
- Karhu, O., Kansi, P. and Kuorinka, I., 1977. Correcting working postures in industry: a practical method for analysis. *Applied ergonomics*, 8(4), pp.199-201.
- Keyserling, W.M., 2000. Workplace risk factors and occupational musculoskeletal disorders, Part 2: A review of biomechanical and psychophysical research on risk factors associated with upper extremity disorders. *AIHAJ-American Industrial Hygiene Association*, 61(2), pp.231-243.
- Kivi, P. and Mattila, M., 1991. Analysis and improvement of work postures in the building industry: application of the computerised OWAS method. *Applied ergonomics*, 22(1), pp.43-48.
- Kuijer, P.P.F., Verbeek, J.H., Visser, B., Elders, L.A., Van Roden, N., Van den Wittenboer, M.E., Lebbink, M., Burdorf, A. and Hulshof, C.T., 2014. An evidence-based multidisciplinary practice guideline to reduce the workload due to lifting for preventing work-related low back pain. *Annals of occupational and environmental medicine*, 26(1), p.16.
- Kumar, S., 1990. Cumulative load as a risk factor for back pain. *Spine*, 15(12), pp.1311-1316.
- Lee, J. and Nussbaum, M.A., 2013. Experienced workers may sacrifice peak torso kinematics/kinetics for enhanced balance/stability during repetitive lifting. *Journal of biomechanics*, 46(6), pp.1211-1215.
- Muslim, E., Nurtjahyo, B. and Ardi, R., 2011. Ergonomic Analysis of Garment Industry using Posture Evaluation Index (PEI) in Virtual Environment. *Makara Journal of Technology*, 15(1), pp.75-81.
- Nelson, N.A. and Hughes, R.E., 2009. Quantifying relationships between selected work-related risk factors and back pain: a systematic review of objective biomechanical measures and cost-related health outcomes. *International Journal of Industrial Ergonomics*, 39(1), pp.202-210.
- Norman, R., Wells, R., Neumann, P., Frank, J., Shannon, H., Kerr, M. and Study, T.O.U.B.P., 1998. A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clinical biomechanics*, 13(8), pp.561-573.
- Panel on Musculoskeletal Disorders, A., the Workplace and Institute of Medicine, 2001. *Musculoskeletal disorders and the workplace: Low back and upper extremities*. National Academy Press.

- Plamondon, A., Denis, D., Delisle, A., Larivière, C., Salazar, E. and IRSST MMH research group, 2010. Biomechanical differences between expert and novice workers in a manual material handling task. *Ergonomics*, 53(10), pp.1239-1253.
- Plamondon, A., Delisle, A., Bellefeuille, S., Denis, D., Gagnon, D., Larivière, C. and IRSST MMH Research Group, 2014. Lifting strategies of expert and novice workers during a repetitive palletizing task. *Applied ergonomics*, 45(3), pp.471-481.
- Raschke, U., 1996. Lumbar muscle activity prediction under dynamic sagittal plane lifting conditions: Physiological and biomechanical modeling considerations.
- Simon, J., 1991. *Ergonomics: The study of work*. US Government Printing Office.
- Singh, J., Lal, H. and Kocher, G., 2012. Musculoskeletal disorder risk assessment in small scale forging industry by using RULA method. *International Journal of Engineering and Advanced Technology*, 1(5), pp.513-518.
- Tee, K.S., Low, E., Saim, H., Zakaria, W.N.W., Khialdin, S.B.M., Isa, H., Awad, M.I. and Soon, C.F., 2017, September. A study on the ergonomic assessment in the workplace. In *AIP Conference Proceedings* (Vol. 1883, No. 1, p. 020034). AIP Publishing LLC.
- Waters, T., Occhipinti, E., Colombini, D., Alvarez-Casado, E. and Fox, R., 2016. Variable Lifting Index (VLI) A New Method for Evaluating Variable Lifting Tasks. *Human factors*, 58(5), pp.695-711.
- Vander Molen, H.F., Grouwstra, R., Kuijter, P.P.F., Sluiter, J.K. and Frings-Dresen, M.H., 2004. Efficacy of adjusting working height and mechanizing of transport on physical work demands and local discomfort in construction work. *Ergonomics*, 47(7), pp.772-783.
- Waters, T., Occhipinti, E., Colombini, D., Alvarez-Casado, E. and Fox, R., 2016. Variable Lifting Index (VLI) A New Method for Evaluating Variable Lifting Tasks. *Human factors*, 58(5), pp.695-711.
- Waters, T., Occhipinti, E., Colombini, D., Alvarez, E. and Hernandez, A., 2009. The Variable Lifting Index (VLI): a new method for evaluating variable lifting tasks using the Revised NIOSH Lifting Equation. *NIOSH-Cincinnati, Ohio (USA), CEMOC-EPM Foundation Policlinico Mangiagalli-Milano (Italy), Research Unit EPM-Foundation Don Gnocchi onlus-Milano (Italy), Center for Ergonomics and Prevention (CERPIE)-UPC-Barcelona (Spain)*.
- Waters, T.R., Putz-Anderson, V., Garg, A. and Fine, L.J., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics*, 36(7), pp.749-776.

Biographies

Afifa Sumaya is a novice researcher and final year undergraduate student in the Department of Industrial & Production Engineering (IPE), BUET. Her research interest includes operations research, reliability analysis, supply chain management, machine learning and data science.

Aquib Irteza Reshad is a novice researcher and final year undergraduate student in the Department of Industrial & Production Engineering (IPE), BUET. His research interest includes operations research, supply chain management, total quality management, machine learning and data science.

Newsheen Sharmili is a postgraduate student of the Department of Industrial & Production Engineering (IPE), BUET. Her research interest involves operations research, ergonomics, probabilistic methods in engineering designs, multidisciplinary system optimization, uncertainty analysis, machine learning, and artificial intelligence.

Muniom Shahriar is a novice researcher and final year undergraduate student in the Department of Industrial & Production Engineering (IPE), BUET. He has huge interests in supply chain management, risk management.