ROCHESTER INSTITUTE OF TECHNOLOGY

Manual Material Handling

Evaluating Lifting Guidelines
Modify Workplace Design

ABIGAIL HIGGINS – GWENDOLYN NEUHAUS – NICK MORRIS

3/13/2015

Contents

Introduction

Injuries due to manual material handling (MMH) result in the largest single source of worker compensation costs (Dempsey & Hashemi 1999). In 1994, US companies spent $30 billion in workers compensation costs associated with MMH injuries. Completely eliminating MMH in the workplace is near impossible, but it can be significantly reduced with new technologies and the redesigning of current processes. Many companies are held back from significantly reducing their MMH due to the cost of new automation technologies. There is also the issue of a lack of space to install machines since most manufacturing floors have a carefully laid out floor plan. MMH will have a place in the workplace for years to come due to the diverse nature of tasks that need to be completed (Mital 1999). Most MMH injuries are due to overexertion and can be prevented with the implementation of redesigned processes and practices.

The most common type of MMH injury is a strain to the lower back, accounting for 51.3% of total claims. Lower back and upper extremities are the most common site of injury, taking credit for 70% of all claims. Lower back injury rates are due to a multitude of factors including height, weight, age, strength, and posture. 80% of workers experience a lower back injury in their career (Davis & Seol 2005). These injuries are usually caused by overexertion due to heavy lifting or awkward postures and movements completed on a daily basis.

The National Institute for Occupational Safety and Health (NIOSH) developed a lifting equation in 1991 designed to highlight when workers are at an increased risk for lower back injuries. In 2002, Elfeituri and Taboun evaluated the NIOSH lifting equation for its affectability in real-life situations. The NIOSH lifting index (LI) considers values below 1 a safe lift, values between 1 and 3 a risk for some people and values above 3 put almost everybody at risk for a lower back injury. The psychophysical study conducted by Elfeiture and Taboun in 2002 consisted of 13 volunteers performing tasks with various angles of twist and frequencies. The recommended weight limit (RWL) and LI were calculated for each participant at each lifting condition. The average LI was 2.79 when the frequency was 3 lifts per minute and 4.89 at 6 lifts per minute. The study concluded that the maximum allowable horizontal distance of 25cm in the RWL calculation is too restricting as many MMH jobs require a horizontal distance greater than 25cm. However, the frequency factor was the most restricting part of the equation, resulting in unrealistic and expensive expectations (Elfeituri & Taboun 2002).

The NIOSH LI equation also doesn't take into account the angular position, velocity, and acceleration of the trunk (Elfeituri & Taboun 2002). The equation assumes that workers stand still and twist their torso while in reality most workers will do a step-turn to make the lift. Most people simply can't twist very far comfortably while holding weight without moving their feet to compensate for the shift in weight (Han, Stobbe, & Hobbs 2005).

There was no significant increase or decrease in the number of MMH claims between 1990 and 1995. This could be because new items and processes are constantly being developed without giving enough time for ergonomic standards to catch up any ground. It could also be because there isn't enough focus put into improving ergonomic environments for workers (Dempsey & Hashemi 1999). One speculation as to why the number of claims hasn't gone up is the survivor effect. The survivor effect is the selection of the fittest workers for MMH jobs. Workers who are not predisposed for heavy lifting and manual labor will tend to not spend long in a MMH job. As the number of years on the job increases, the LI capacity on average also increases. This can lead to a "healthy worker effect" in which the overall injury rate is lower than expected (Waters et al. 1999).

Many MMH injuries can be avoided if preventative practices are put into effect before the injuries occur. Gravity should be used to help with tasks whenever possible and many small breaks are more beneficial health wise than one long break. The biomechanical limits of the body should be considered when tasks are assigned. Compression limits on the spine are usually calculated using the spinal fractures of cadavers and maximum joint torque data is usually collected by studying the voluntary movement of subjects. Static and dynamic models showing what workers can accomplish without injury are created using the compression and torque data. Dynamic models, while harder to create, are preferred as most MMH is composed of dynamic movement and static models tend to underestimate the added stress of movement. The physiological approach focuses on preventing whole-body and local fatigue. The energy expenditure is measured by oxygen consumption as a percentage of maximum aerobic capacity. This approach runs into problems as it is expensive to measure and aerobic capacity is very task specific (Dempsey 1998).

Objective studies on human capacities are more expensive and harder to perform than self-reporting studies because they usually rely on heart monitors, electronic motion sensors, and other equipment. Psychological self-reported studies, such as the Liberty Mutual Tables, are less expensive, easy to understand, and are usually fairly reliable. They are also preferable when the population who will be using the techniques can be reported on directly. In a study conducted by Skatrud-Mickelson, Benson, Hannon, and Askew in 2011, subjective and objective measurements of physical exertion were compared. The participants were asked to run three laps and rate each lap using the Borg Rating Scale of Perceived Exertion. These values were compared to the readings of accelerometers. Most people participating in the study underestimated their physical activity exertion in the 3rd lap. Overestimating wasn't very common in the study, but it was more frequent in women than men (Skatrud-Mickelson, Benson, Hannon, & Askew 2011).

Objectives/Hypothesis

The following lab was designed to use the NIOSH lifting guidelines and Liberty Mutual tables to analyze manual material handling tasks. Data was collected on the tasks and analyzed in order to recommend modifications to the workplace design with the goal of accommodating more people. It was hypothesized that the tasks analyzed will put the worker at a high risk of injury due to the weight of the motors and the precision with which the bins are placed on the cart. The lifting index was estimated to be above 2 with the limiting task being the placing of the lowest bin on the cart. It is estimated that a majority of females aren't capable of performing the tasks without an increased risk of developing lower back disorders.

Methodology

The subjects for this analysis were three undergraduate students, two females and one male, in Group 11 of the RIT Ergonomics and Human Factors Course in the spring of 2015. The testing apparatus consisted of equipment and two manual material handling analysis methods. The equipment used by group 11 was a tape measure and a push/pull gauge. The analysis methods and corresponding documentation used were NIOSH: *Applications for the Revised Lifting Equation (1994)* and Liberty Mutual: *Manual Materials Handling Guidelines (2015)*. The NIOSH analysis is based on physiological, biomechanical, psychophysical, and epidemiological methodologies. The Liberty Mutual Analysis is based on Psychophysical methodology.

The environment for this analysis was the RIT TPS Lab. The conditions of the environment were the equipment, lighting, temperature, and the physical layout for the operation. The equipment consisted of plastic crates with side handles, and filled with motors for a total weight of 40 [lbs] per crate. There was a roller conveyor system to transport and hold a queue of one to four crates. The conveyor was assumed to be powered such that the subjects would lift each crate off of the end of the conveyor for the duration of the operation. The last piece of equipment was the plastic cart with wheels, and designed to hold four crates. Crate 1 is placed on cart level 1 and this action is considered as task 1; the remaining tasks follow the same relationship. The cart was positioned such that the top level would decline away from the operator. The lighting in the TPS Lab was bright enough for the subjects to see during the operation without having to deal with a glare. The temperature was room temperature, assumed to be within the productive comfort zone of 70 – 75 degrees Fahrenheit for the duration of the operation. The physical layout of the equipment was in a linear production line with an approximate four foot aisle width on each side of the conveyor so that one person has the clearance to push/pull the cart.

The first measurement procedure conducted by Group 11 was for the NIOSH metrics. The male subject performed the set of four tasks first, one female subject would gather the NIOSH metrics, and another female subject recorded the values for each metric. The three subjects rotated until each one performed all four tasks and there were three sets of NIOSH metrics, which were then averaged together for the input values in the NIOSH Lifting Equation. The object's weight was given as 40 [lbs]. The origin horizontal hand location was measured with a tape measure. The subject stood straight holding the crate in a static position while the crate sat on the conveyor. The measurement was the distance from the subject's knuckles to the projected mid-point of the subject's ankles. The origin vertical hand location was measured with a tape measure. The measurement was the distance from the floor to the handles of the crate while positioned on the conveyor. The destination horizontal hand location was measured with a tape measure. The subject remained in a static squatting position while holding the crate and resting it on its corresponding level in the cart. The measurement was the distance from the subject's knuckles to the projected mid-point of the subject's ankles. This measurement was replicated a total of four times to obtain the metrics for each of the four tasks. The origin asymmetry measurement was determined visually. The subject grabbed the crate while facing it and without needing to rotate the crate at any point as it sat on the conveyor. The destination asymmetry was determined visually. The subject needed to rotate the crate for task 1, 2, and 3 to access the inside of the cart's frame without bumping into it. The subject placed the 4^{th} crate on the top of the cart and let it slide into place while facing it and without needing to rotate the crate at any point. The frequency rate was given based on a 6 minute return time for the cart. The duration was assumed to be 8 hours to represent a typical work shift. The coupling was good for each task because each crate had handles for the subjects to grab. Significant control was present for tasks 1, 2, and 3 because the subject had to rotate the crate and carefully place the crate inside the cart without bumping into the frame of the cart. Significant control wasn't present for task 4 because the subject placed the crate on the top bar of the cart and let the crate itself slide into place.

The second measurement procedure conducted by Group 11 was for the Liberty Mutual metrics. The Liberty Mutual metrics for Lowering, tasks 1 – 3, and Lifting, task 4, were taken as the NIOSH metrics were measured. The object's weight remains the same. The lifting distance metrics for each level were the same as the corresponding values for the NIOSH vertical distance metric. The hand distance metrics were measured with a tape measure. The subject's position for each task was the same as described in the NIOSH destination horizontal hand distance measurements. The distances were from the subject's knuckles to the front of the subject's body for each of the four tasks. The frequency metric was based on a 6 minute return time for the cart.

The Liberty Mutual metrics for pushing and pulling the cart were taken after tasks 1 to 4 had been completed. The male subject used the push/pull gage to measure the initial and sustained push and pull force metrics. One female subject guided the cart to maintain stability for accurate measurements. Another female subject recorded the measurements. The travel distance metric was measured with a tape measure. The distance was the length of the roller conveyor system. The hand height metric was measured with a tape measure. The measurement was the distance from the floor to the top bar of the cart. The frequency metric was based on a 6 minute return time for the cart.

Results

Using the collected data the group can use the NIOSH equation and the Liberty Mutual method to determine the lifting index and the percentage of males and females that can accomplish this task. From the NIOSH method it can be concluded that this system has a lifting index of 3.9. However the Liberty Mutual method expressed that less than 10% of females can do the lifting and lowering portion of the system but more than 90% can push or pull the cart. Whereas 81% of males can lower the first crate, 83% can lower the second crate, 85% can lower the third crate, and 85% can lift the final crate. Over 90% of males can push or pull the cart.

Figure 1 illustrates the proportions of the cart's front view. All measurements were taken in relation to the starting point which in this case is the conveyor belt. It displays the distance that each box had to be moved; the first crate was lowered 22 inches, crate 2 was lowered 16 inches, crate three was lowered 11 inches, and crate 4 had to be lifted 9 inches.

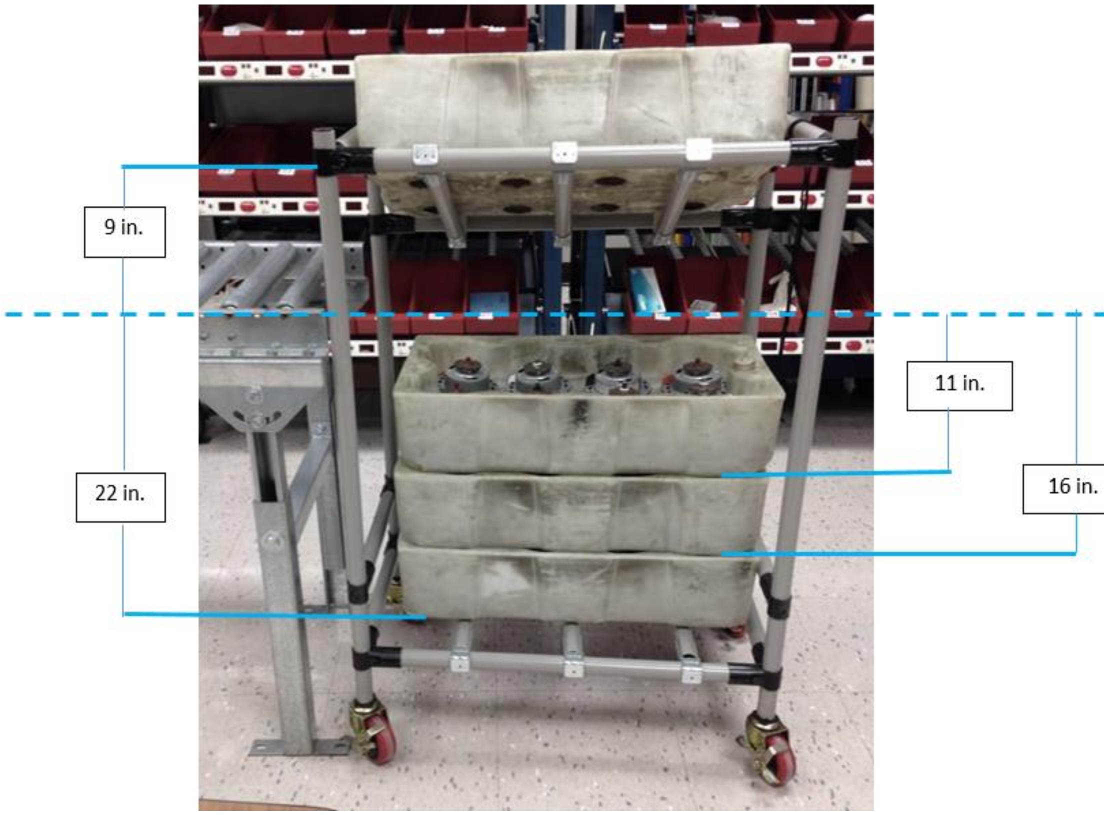

Figure 1: The front dimensions of a fully loaded cart.

Figure 2 displays the side view of a fully loaded cart. The overall height of the cart was 37.5 inches. The top shelf was at a 60^{o} angle with the vertical, allowing the load to be slide into place. At the lifting point in the process the worker is closest to the cart with only 2 inches of separation.

Figure 2: The side dimensions of a fully loaded cart.

Figure 3 shows the largest distance the worker stands from the cart. When the worker has to lower the crate the distance from the cart is at its highest point of 12 inches. They are this far from the cart for all lowering tasks.

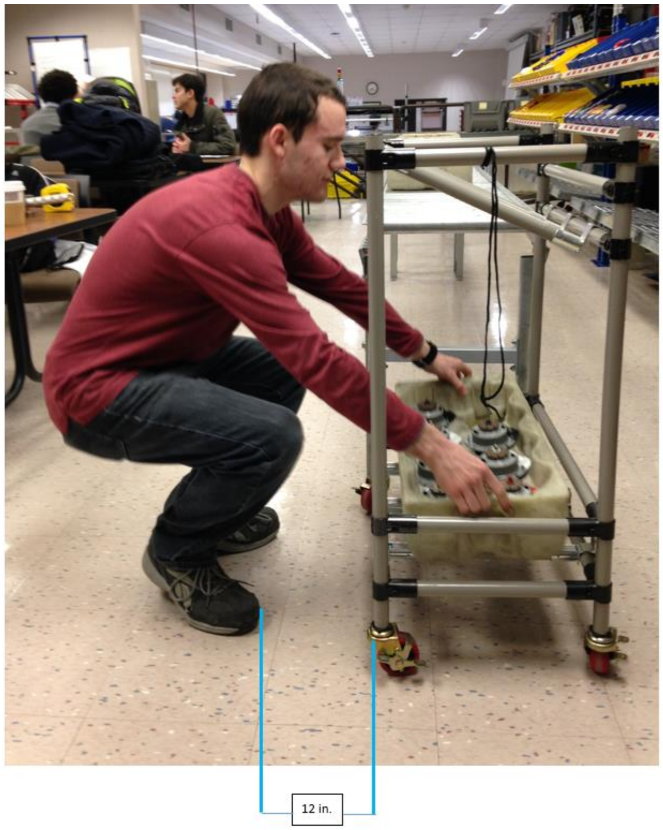

Figure 3: The farthest standing distance from the cart.

Figure 4 is a side view of the entire conveyor belt. Once the cart is fully loaded it is pushed or pulled from the right end to the left end of the belt, a total distance of 242 inchest.

Figure 4: The distance the cart has to be pushed or pulled.

Table 1 below has the RWL and LI for each lift/lower of the four crates, as well as the composite lifting index (CLI) for the overall operation as indicated by the colored cells. The frequency independent recommended weight limit (FIRWL) for tasks 1, 2, 3, and 4 are 68%, 65%, 62%, and 31% lower than the crate weight of 40 lbs respectively. The single task recommended weight limit (STRWL) for tasks 1, 2, 3, and 4 are 73%, 71%, 67%, and 41% lower than the crate weight of 40 lbs respectively. The RWL for each of the tasks show a large gap between what the job requires and what NIOSH recommends, whether the frequency multiplier (FM) is ignored for the FIRWL or isn't ignored for the STRWL.

The frequency independent lifting index (FILI) and single task lifting index (STLI) both show a trend of decreasing in value throughout the order of the operation in tasks 1 – 4. This is due to the tasks decreasing in physical stress as the tasks progress, which is indicated by the horizontal multiplier (HM), vertical multiplier (VM), distance multiplier (DM), and asymmetric multiplier (AM) approaching 1. The decreasing values of both LI indicate that there is less risk in lower back pain for the operators from tasks 1 – 4. Task 4 proves to have the least amount of risk with FILI and STLI values of 1.0 and 1.2 respectively. According to NIOSH there is still an increased risk for some workers posed by lifting task 4 because the lifting indexes have values greater than or equal to 1. The remaining tasks show that many or most workers are at a high risk of developing lower back pain and injury due to values greater than 3 for STRWL.

The CLI shows a large value of 3.9 for the entire operation according to the NIOSH Lifting Equation. This suggests that this operation is posing a large risk of lower back pain and injury for most operators who perform these four tasks on a daily basis as their job. See *Worksheet 1: NIOSH Multi-Task Job Analysis* in the Appendix for the full data set and assumptions.

Recommended Weight Limits and Lifting Indexes

Task No.	LC	x HM	x VM	x DM	x AM	x CM	= FIRWL	x FM	= STRWL	FILI = L/FIRWL	STLI = L/STRWL	New Task No.	F
1	51	0.40	0.81	0.90	0.86	1.00	12.8	0.85	10.9	3.1	3.7	1	0.166667
2	51	0.40	0.85	0.93	0.86	1.00	13.9	0.85	11.8	2.9	3.4	2	0.166667
3	51	0.40	0.89	0.98	0.86	1.00	15.3	0.85	13.0	2.6	3.1	3	0.166667
4	51	0.78	0.98	1.00	1.00	1.00	39.0	0.85	33.1	1.0	1.2	4	0.166667

Composite Lifting Index

CLI =	$STLI_1$	+ $\Delta FILI_2$	+ $\Delta FILI_3$	+ $\Delta FILI_4$	+ $\Delta FILI_5$	
		$FILI_2\,(1/FM_{1,2} - 1/FM_1)$	$FILI_3\,(1/FM_{1,2,3} - 1/FM_{1,2})$	$FILI_4\,(1/FM_{1,2,3,4} - 1/FM_{1,2,3})$	$FILI_5\,(1/FM_{1,2,3,4,5} - 1/FM_{1,2,3,4})$	
CLI =	3.7	0.17	0.00	0.00		3.9

Table 1: NIOSH Lifting Equation Results

Table 2 below shows that the percentages of the female and male population that are capable of performing each of the four tasks, lifting/lowering each of the four crates, based on the Liberty Mutual tables. The Liberty Mutual tables used for the results are indicated above the data tables for female and male. The colored cells indicate the limiting task(s) for the operation. The female population shows no indication on which task is most limiting in the operation because all four tasks can be completed by less than 10% of the female population without an increased risk in low back disability.

The male population shows that the limiting task in the operation is task 1 based on 81% of the male population capable of performing the task without an increased risk in lower back disability. Notice that the percentages of the male population increases from task 1 – 4 which can also be assumed is the trend for females despite the lack of specification in the Liberty Mutual Tables. See *Worksheet 2: Liberty Mutual Job Analysis* in the Appendix for the assumptions and linear interpolation calculations.

Female Population Percentages for Lifting/Lowering Tasks

Tables: 2F, 4F

Crate:Task	Object Weight (lbs)	Lifting Distance [in]	Hand Distance [in]	Frequency: 1 Lift Every X [min]	Percentage %
1:Lower	40	22	25	6	< 10
2:Lower	40	17	25	6	< 10
3:Lower	40	12	24	6	< 10
4:Lift	40	9	13	6	< 10

Male Population Percentages for Lifting/Lowering Tasks

**Linearly Interpolated*

Tables: 2M, 4M

Crate:Task	Object Weight (lbs)	Lifting Distance [in]	Hand Distance [in]	Frequency: 1 Lift Every X [min]	Percentage %
1:Lower	40	22	25	6	81*
2:Lower	40	17	25	6	83*
3:Lower	40	12	24	6	85*
4:Lift	40	9	13	6	85*

Table 2: Liberty Mutual Lifting/Lowering Percentages

Table 3 below shows what percentage of the female and male population are capable of performing each of the four tasks, push (initial and sustained) and pull (initial and sustained), based on the Liberty Mutual Tables. The Liberty Mutual Tables used for the results are indicated above the data tables for female and male. There is no indication of a limiting task in this operation due to more than 90% of the population for females and males being able to perform these tasks without an increased risk in low back disability. See *Worksheet 2: Liberty Mutual Job Analysis* in the Appendix for the assumptions.

The percentage of the female population capable of performing the entire operation of loading the cart and transporting it every 6 minutes without an increased risk in low back disability is less than 10%. This is due to the loading of each crate in the cart as the limiting factors for females. The percentage of the male population capable of performing the entire operation of loading the cart and transporting it every 6 minutes without an increased risk in low back disability is 81%. The lowering of the 1st crate in the cart is the limiting factor for males.

Female Population Percentages for Pushing/Pulling Tasks

Tables: 7, 8F, 9, 10F

Task	Push/Pull Force (lbs)	Travel Distance [ft]	Hand Height [in]	Frequency: 1 Push/Pull Every X [min]	Percentage %
Initial:Push	10	-	38	6	> 90
Sustained:Push	4	20	38	6	> 90
Initial:Pull	10	-	38	6	> 90
Sustained:Pull	4	20	38	6	> 90

Male Population Percentages for Pushing/Pulling Tasks

Tables: 7, 8M, 9, 10M

Task	Push/Pull Force (lbs)	Travel Distance [ft]	Hand Height [in]	Frequency: 1 Push/Pull Every X [min]	Percentage %
Initial:Push	10	-	38	6	> 90
Sustained:Push	4	20	38	6	> 90
Initial:Pull	10	-	38	6	> 90
Sustained:Pull	4	20	38	6	> 90

Table 3: Liberty Mutual Pushing/Pulling Percentages

Discussion

The results of the NIOSH and Liberty Mutual analysis method make sense and seem reasonable. Using the NIOSH method it was determined that this system has a CLI of 3.9, displaying that is extremely tasking with a large risk of a back injury. The Liberty Mutual analysis expressed that less than 10% of females would be able to load each of the crates into the cart but more that more than 90% would be able to push or pull the cart. This indicates that the lowering/lifting tasks are equally the most demanding aspects of the task for females. Whereas for males 81% could load the first crate, 83% could load the second crate, 85% could load the third crate, and 85% could load the fourth crate. More than 90% of males could push or pull the cart. This shows that lowering the first crate is the most demanding aspect of the task for males. It was extremely difficult to bend over and place such a large load into such a narrow cart. Since the width of the cart was so small, the operator needed to twist their torso in order to get the crate in and significant control was required. Overall, because this is such a challenging system the results of the analysis supported all hypothesizes. The lifting index was over 2 and more than 50% of female aren't capable of completing the task without an increased risk of lower back injury.

It can be concluded that the NIOSH and Liberty Mutual methods have some variation. The Liberty Mutual method is able to draw a conclusion for men and women separately, while the NIOSH method draws a conclusion for the general population. As a result the two methods came to different conclusions for the male population. NIOSH suggests that it is very likely for anyone loading the cart to receive a back injury, whereas the Liberty Mutual method purposes that more than 80% of men could load this cart without an increased risk. This illustrates that because the two methods use different pieces of data, they yield different results. However, the NIOSH lifting index is consistent with the female Liberty Mutual results. Both suggest that the system has a high risk of back pain for the female population.

Some aspects of this system are already ergonomically friendly. The cart has very little friction with the floor making it easy for the worker to transport the load. The angled top shelf makes placing the crate easier since they only have to lift the crate, and gravity places it on the rack. However, a variety of changes could help make the tasks safer for the worker as summarized in Table 4. One possibility would be to slightly curve the front side bars so they bowed outwards. This solution would create enough space to fit both the crate and the workers hands, removing the need to twist while placing the crate. Eliminating asymmetry can help reduce the likelihood of back injury. Another way to decrease the chance of injury would be decrease the distance that the worker has to move the load. An increase in the angle between of the top shelf and the vertical would decrease the overall height of the top shelf. If two vertical bars were added to the back of the cart a wedge could be added to the bottom shelf so all the crates are parallel. With this additional angle workers will simply need to lower the crate to the desired height and gravity will place it for them. The risk that comes with the placement precision would be eliminated. Once a wedge is added, the bottom shelf could be raised slightly, decreasing the distance that the crate has to be lowered. A few small changes could significantly change the amount of risk the worker is exposed to.

Ergonomic Suggestions	Benefit
Bow Out Front Bars	Removes Asymmetry for Tasks 1 - 3
Increase the Angle of the Top Shelf from the Vertical	Decrease the Lifting Distance for Task 4
Add a Wedge at the Bottom of the Cart for Angled Levels	Reduces Lower Back Load due to Placement Precision
Add Two Vertical Bars at the Back of the Cart	Removes Significant Control from the Operator
Slightly Raise the Height of the Bottom Level	Reduce the Lowering Distance to Reduce Lower Back Load

Table 4: Ergonomic Suggestions

There are several limitations on both the NIOSH method and the Liberty Mutual method. Both are very task specific, therefore the results can't be transferred from one system to another. The two methods have to be repeated for all the tasks at hand. Another issue is that both only focus on lower back issues, they don't highlight the possibility of other body parts being at risk. For example, in the system that was evaluated above the operator had to extend their arms to place the crates. This motion could increase the likelihood of shoulder injury but neither method addresses that possibility. Displaying that to truly understand the amount of risk a worker is under multiple analysis need to be performed.

Works Cited

Davis, K., Seol, H. (2005) Injury-induced kinematic compensations within the lower back: impact of non-lower back injuries, Ergonomics, 48:2, 135-149, DOI: 10.1080/0014013051233131931

Dempsey, P. (1998) A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks, Ergonomics, 41:1, 73-88, DOI: 10.1080/001401398187332

Dempsey, P.G., Hashemi, L. (1999) Analysis of workers' compensation claims associated with manual materials handling, Ergonomics, 42:1, 183-195, DOI: 10.1080/001401399185883

Elfeituri, F.E., Taboun, S.M. (2002) An Evaluation of the NIOSH Lifting Equation: A Psychological and Biomechanical Investigation, International Journal of Occupational Safety and Ergonomics, 8:2, 243-258, DOI: 10.1080/10803548.2002.11076527

Han, B., Stobbe, T.J., Hobbs, G.R. (2005) The effect of asymmetry on psychological lifting capacity for three lifting types, Ergonomics, 48:4, 364-379, DOI: 10.1080/00140130512331332928

Mital, A. (1999) Analysis of multiple activity manual materials handling tasks using A Guide to Manual Materials Handling, Ergonomics, 42:1, 246-257, DOI: 10.1080/001401399185928

Skatrud-Mickelson, M., Benson, J., Hannon, J.C., Askew, E.W., (2011) A comparison of subjective and objective measures of physical exertion, Journal of Sports Sciences, 29:15, 1635-1644, DOI: 10.1080/02640414.2011.609898

Waters, T.R., Baron, S.L., Piacitelli, L.A., Anderson, V.P., Skov, T., Haring-Sweeney, M., … Fine, L.J. (1999) Evaluation of the Revised NIOSH Lifting Equation, SPINE, 24:4. http://www.cdc.gov/niosh/awards/hamilton/pdfs/hum_5.pdf

Appendix

Figure 5: The asymmetry required to place the first three crates.

Multi-Task Job Analysis Worksheet

Department	Industrial & Systems Engineering
Job Title	Manual Material Handling Analysis
Analaysts	Nick Morris, Gwen Neuhaus, Abby Higgins
Date	3/16/2015

Job Description

A worker lifts four crates *(Task No.)* of motors off a "Feed Conveyor" one one at a time and puts them on a cart. Three crates are stacked on the bottom and one is placed on the top.

Task Variable Data

Task No.	Object Weight (lbs)		Hand Location (in)				Vertical Dist. (in)	Assymetry (deg)		Freq. Rate lifts/min	Duration (hrs)	Coupling	Significant Control?
			Origin		Destination			Origin	Dest.				
	L (Avg)	L (Max)	H	V	H	V	D	A	A	F		C	
1	40	40	13	27	25	5	22	0	45	0.167	≤ 8 Hrs	Good	Y
2	40	40	13	27	25	11	17	0	45	0.167	≤ 8 Hrs	Good	Y
3	40	40	13	27	25	16	12	0	45	0.167	≤ 8 Hrs	Good	Y
4	40	40	13	27	13	36	9	0	0	0.167	≤ 8 Hrs	Good	N

Assumptions:

This task was performed with the orientation of the cart positioned such that the top shelf would decline away from the operator. The Object Weight was given as 40 lbs. The Origin Horizontal Hand Distance was the average of the Analysts'' distances. The Origin Vertical Hand Distance was the distance from the floor to the handle of the crate on the conveyor. The Destination Horizontal Hand Distance was the average of the Analysts' distances. The values for tasks 1 - 3 were larger than the maximum 25 [in]. The Destination Vertical Hand Distance used was the distance from the floor to the handle of the crate on each of the respective levels (level 1 Bottom = task 1, level 2 = task 2, level 3 = task 3, level 4 Top = level 4). The Origin Asymmetry was 0 because the operator would step to the right after lifting the crate to position his or herself in front of the cart. The Destination Asymmetry was 45 for tasks 1 -3 because the operator would rotate the crate 45 degrees to access the lower carts entry points without bumping into the frame with their hands. The Destination Asymmetry was 0 for task 4 because the operator could access the top entry point without hitting the frame. The Frequency Rate was calculated based on the 6 minute cart return time. The Duration was assumed to be 8 hours for a regular work shift. The Coupling was good due to the crates have handles. The Significant Control was 'Yes' for tasks 1 - 3 due to the extra time needed to place the crate without bumping the light cart. The Significant Control was 'No' for task 4 because the operator could easily rest the crate onto the top of the frame and let the crate slide down into place.

Recommended Weight Limits and Lifting Indexes

Task No.	LC	x HM	x VM	x DM	x AM	x CM	= FIRWL	x FM	= STRWL	FILI = L/FIRWL	STLI = L/STRWL	New Task No.	F
1	51	0.40	0.81	0.90	0.86	1.00	12.8	0.85	10.9	3.1	3.7	1	0.166667
2	51	0.40	0.85	0.93	0.86	1.00	13.9	0.85	11.8	2.9	3.4	2	0.166667
3	51	0.40	0.89	0.98	0.86	1.00	15.3	0.85	13.0	2.6	3.1	3	0.166667
4	51	0.78	0.98	1.00	1.00	1.00	39.0	0.85	33.1	1.0	1.2	4	0.166667

Composite Lifting Index

CLI =	$STLI_1$	+ $\Delta FILI_2$	+ $\Delta FILI_3$	+ $\Delta FILI_4$	+ $\Delta FILI_5$	
		$FILI_2\,(1/FM_{1,2} - 1/FM_1)$	$FILI_3\,(1/FM_{1,2,3} - 1/FM_{1,2})$	$FILI_4\,(1/FM_{1,2,3,4} - 1/FM_{1,2,3})$	$FILI_5\,(1/FM_{1,2,3,4,5} - 1/FM_{1,2,3,4})$	
CLI =	3.7	0.17	0.00	0.00		3.9

Worksheet 1: NIOSH Multi-Task Job Analysis

Liberty Mutual Job Analysis Worksheet

Department	Industrial & Systems Engineering	**Job Description**	
Job Title	Manual Material Handling Analysis	A worker lifts four crates of motors off a conveyor and puts them on a cart. Three are stacked on the bottom and one on the top. The cart is pushed to the end of the conveyor.	
Analaysts	Nick Morris, Gwen Neuhaus, Abby Higgins		
Date	3/16/2015		

Female Population Percentages for Lifting/Lowering Tasks

Tables: 2F, 4F

Crate:Task	Object Weight (lbs)	Lifting Distance [in]	Hand Distance [in]	Frequency: 1 Lift Every X [min]	Percentage %
1:Lower	40	22	25	6	< 10
2:Lower	40	17	25	6	< 10
3:Lower	40	12	24	6	< 10
4:Lift	40	9	13	6	< 10

Assumptions:
Table 2F: Object Weight 38 and 41 [lbs] rows were used for 40. Lifting Distance 20 and 30 [in] rows were used for 22; 10 and 20 [in] rows were used for 17 and 12. Hand Distance 15 [in] column was used for 25 and 24. Frequency Column 5[min] was used for 6. Table 4F: Object Weight 39 and 41 [lbs] rows were used for 40. Lifting Distance 10 [in] row was used for 9. Hand Distance 10 and 15 [in] columns were used for 13. Frequency Column 5[min] was used for 6.

Male Population Percentages for Lifting/Lowering Tasks

**Linearly Interpolated*

Tables: 2M, 4M

Crate:Task	Object Weight (lbs)	Lifting Distance [in]	Hand Distance [in]	Frequency: 1 Lift Every X [min]	Percentage %
1:Lower	40	22	25	6	81*
2:Lower	40	17	25	6	83*
3:Lower	40	12	24	6	85*
4:Lift	40	9	13	6	85*

Assumptions:
See Linear Interpolation Table in Appendix for the Liberty Mutual table values used for each task.

Female Population Percentages for Pushing/Pulling Tasks

Tables: 7, 8F, 9, 10F

Task	Push/Pull Force (lbs)	Travel Distance [ft]	Hand Height [in]	Frequency: 1 Push/Pull Every X [min]	Percentage %
Initial:Push	10	-	38	6	> 90
Sustained:Push	4	20	38	6	> 90
Initial:Pull	10	-	38	6	> 90
Sustained:Pull	4	20	38	6	> 90

Assumptions:
Table 7: The initial push forces available were significantly higher than 10 so a > 90 percentile value was assumed. Table 8F: The sustained push forces available were significantly higher than 4 so a > 90 percentile value was assumed. Table 9: The initial push forces available were significantly higher than 10 so a > 90 percentile value was assumed. Table 10F: The sustained push forces available were significantly higher than 4 so a > 90 percentile value was assumed.

Male Population Percentages for Pushing/Pulling Tasks

Tables: 7, 8M, 9, 10M

Task	Push/Pull Force (lbs)	Travel Distance [ft]	Hand Height [in]	Frequency: 1 Push/Pull Every X [min]	Percentage %
Initial:Push	10	-	38	6	> 90
Sustained:Push	4	20	38	6	> 90
Initial:Pull	10	-	38	6	> 90
Sustained:Pull	4	20	38	6	> 90

Assumptions:
Table 7: The initial push forces available were significantly higher than 10 so a > 90 percentile value was assumed. Table 8M: The sustained push forces available were significantly higher than 4 so a > 90 percentile value was assumed. Table 9: The initial push forces available were significantly higher than 10 so a > 90 percentile value was assumed. Table 10M: The sustained push forces available were significantly higher than 4 so a > 90 percentile value was assumed.

Male Crate 1 - Table 2M					Male Crate 2 - Table 2M				
Hand Distance:		15 in	Freq:	5m	Hand Distance:		15 in	Freq:	5m
Weight	Lift Dist.	Percentile	Linear Factor	Percentile*	Weight	Lift Dist.	Percentile	Linear Factor	Percentile*
	30	76							
42	20	79	0.2	78.4	42	20	79		
						10	85	0.7	80.8
	30	80							
39	20	82	0.2	81.6	39	20	82		
						10	87	0.7	83.5
40	22	81	0.333333333	80.53333333	40	17	83	0.333333333	82.6

Male Crate 3 - Table 2M					Male Crate 4 - Table 4M				
Hand Distance:		15 in	Freq:	5m	Weight:		40	Freq:	5m
Weight	Lift Dist.	Percentile	Linear Factor	Percentile*	Hand Dist.	Lift Dist.	Percentile	Linear Factor	Percentile*
42	20	79			15				
	10	85	0.2	83.8		10	79		
39	20	82			10				
	10	87	0.2	86		10	95		
40	12	85	0.333333333	85.26666667	13	10	85	0.6	85.4

Worksheet 2: Liberty Mutual Job Analysis