Bridging the Gap between Academic Research and Construction Workplaces Using the NIOSH 1991 Lifting Equation

Sang D. Choi, Ph.D., CSP, CPE, Professor
Department of Occupational & Environmental Safety & Health
University of Wisconsin – Whitewater

James G. Borchardt, CSP, CPE, CRIS
Bituminous Insurance Company
Home Office Risk Control
Rock Island, IL
Outline...

- Introduction
- Background
- Objectives
- Methods and procedures
- Results – *Part I*
- Results – *Part II*
- Conclusions
Introduction and Review of Literature

- **WMSDs in Construction**
  - Work-related musculoskeletal disorders (WMSDs) and low back injuries are very common among construction workers (NIOSH, 2007; Holmström & Engholm, 2003).
  - The most commonly reported biomechanical risk factors with at least reasonable evidence for causing WMSDs include excessive repetition, awkward postures, and heavy lifting (da Costa & Vieira, 2010).
  - Many construction occupations/trades still require substantial manual lifting and lowering of materials which often results in overexertion.
    - Overexertion in manual lifting was among the most frequent exposure leading to injury or illness involving days away from work (Bureau of Labor Statistics [BLS], 2010).
  - Workers who must often lift, stoop, kneel, twist, grip, stretch, reach overhead, or work in other awkward positions to do a job are at risk of developing a work-related musculoskeletal disorder (NIOSH, 2007).
Manual materials handling at construction

- How much a worker lifts is left to his or her discretion at the job site!!??
  - Often times weights of construction materials seemed to exceed a worker’s physical capacity and pain or injury to the worker will result (Choi, Proksch, & Borchardt, 2009).
  - Need more data sources available to workers, managers, and health & safety professionals to aid in preventing work-related musculoskeletal disorders and injuries.

- More awareness of construction materials’ weight and task-related specific variables prior to manually lifting or lowering may be as important as how the materials are handled.
In 2008, we as an Academic Researcher and a S&H Practitioner first met at the Construction Safety Conference, Rosemont, IL.

We began discussing how S&H research and resources could be made more useful to practitioners.

- Research to Practice (RtP) initiatives...
- Practice to Research (PtR) initiatives...
SH&E “PtRtP” Model

- Practice to Research (PtR)
- SH&E Continuous Improvement
- Research to Practice (RtP)
Objectives

- To investigate the weights of common construction materials and related physical workloads associated with manual lifting or lowering activities

- To translate academic research into effective prevention “good practices” to reduce risks of work-related musculoskeletal disorders and injuries in the construction workplace
Methods and Procedures

- **Manual Lifting Task Observations**

  - The weight of common materials used by various construction trades was measured at job sites.

  - The NIOSH’s 1991 Lifting Equation components (task variables)
    - were either measured using a tape measure such as the distance between the origin and destination of the lift or
    - observed by the researcher such as the worker’s twisting motion and ability to grasp the materials.

- Manual Lifting Observation Data Collection Sheet was prepared in an Excel spreadsheet
  - After collection in the field, data was then entered into the non-printed excel format for further analysis
Methods and Procedures (cont’d)

- **Data Collection Variables**
  - Subject ID
  - Trade / Occupation
  - Gender
  - Age (years)
  - Construction Materials
  - Weight (lbs)
  - Horizontal Location (in) (Origin / Destination)
  - Vertical Location (in) (Origin / Destination)
  - Vertical Travel Distance (in)
  - Asymmetry Angle (deg) (Origin / Destination)
  - Frequency Rate (lifts / min)
  - Duration (hrs)
  - Object Coupling

- **Warm-up data collection session** – see next…
Graphic Representations of Hand Location and Angle

Ref: NIOSH Publication No. 94-110 (Waters et al., 1994)
Using the NIOSH Lifting Equation

- **Step 1**: Measure and Record Task Variables
  - Origin and Destination

- **Step 2**: Determine Multipliers and RWL
  - Origin and Destination
  - Can only decrease the RWL from optimal 51 lbs

- **Step 3**: Compute Lifting Index
  - Single number representing relative risk of task
The 1991 NIOSH Revised Lifting Equation (Waters et al., 1994)

\[ \text{RWL} = \text{LC} \times \text{HM} \times \text{VM} \times \text{DM} \times \text{AM} \times \text{FM} \times \text{CM} \]

Where,

- **Load Constant (LC):** A constant term in the RWL equation defined as a fixed weight of 23 kg or 51 lb; generally considered the maximum load nearly all healthy workers should be able to lift under optimal conditions (i.e. all the reduction coefficients are unity).
- **Horizontal Multiplier (HM):** A reduction coefficient defined as \(10/H\), for \(H\) measured in inches, and \(25/H\), for \(H\) measured in centimeters.
- **Vertical Multiplier (VM):** A reduction coefficient defined as \((1-(.0075 \times [V-30]))\), for \(V\) measured in inches, and \((1-(.003 \times [V-75]))\), for \(V\) measured in centimeters.
- **Distance Multiplier (DM):** A reduction coefficient defined as \((.82 + (1.8/D))\), for \(D\) measured in inches, and \((.82 + (4.5/D))\), for \(D\) measured in centimeters.
- **Asymmetric Multiplier (AM):** A reduction coefficient defined as \((1-(.0032A))\), has a maximum value of 1.0 when the load is lifted directly in front of the body and decreases linearly as the Angle of Asymmetry (A) increases.
- **Frequency Multiplier (FM):** A reduction coefficient that depends upon the Frequency of Lifting (F), the Vertical Location (V) at the origin, and the Duration of Lifting.
- **Coupling Multiplier (CM):** A reduction coefficient based on the Coupling Classification and Vertical Location of the lift.
The 1991 NIOSH Revised Lifting Equation (cont’d)

- **Recommended Weight Limit (RWL)**
  - The load that most healthy adult workers could lift over a shift without increased risk of back injury

- **Lifting Index (LI)**
  - Relative estimate of physical stress associated with a lifting task
  - \[ LI = \frac{\text{Actual Load Weight}}{\text{RWL}} \]
  - If, \( LI \leq 1 \), Acceptable
  - If, \( LI > 1 \), Unacceptable* ( >3 a sig. risk of injury+)

*LI>1, an increased risk for lifting-related low back pain for some fraction of the work force (Waters et al., 1993)
+LI>3, nearly all workers will be at an increased risk of work-related injury when performing highly stressful lifting tasks (NIOSH Publication No. 94-110)
Using the NIOSH Lifting Equation for Redesign

- Use *individual multipliers* to *identify specific contributors* to injury risk

- Use *Recommended Weight Limit (RWL)* to *design jobs*

- Lifting *Index (LI)* to *prioritize* ergonomic redesign and compare tasks
  - The larger the LI the *greater the likelihood of injury*
  - And the smaller the fraction of workers able to perform the job safely
Results – Part I

Academic Research Project using NIOSH 1991 Equation
Results – Part I

- One hundred forty six tasks were observed in fourteen different occupational (trade) groups
  - carpenter, ceiling installer, dry wall installer, electrician, fitter, floor finisher, floor tile layer, flooring installer, insulator, laborer, mason, painter, plumber, sod layer.

- A total of 292 measurements were taken at the origin and destination of lifting/lowering tasks.
  - The median weight of the construction materials manually lifted/lowered was 30.0lbs with an average weight of 32.9lbs and a range of 1.0lbs to 192.0lbs.
Summary of multipliers and RWL and LI
*(origin and destination)*

<table>
<thead>
<tr>
<th>Total Observations (<em>n</em>=292)</th>
<th>Median</th>
<th>STD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Multiplier (HM)</td>
<td>0.56</td>
<td>0.29</td>
<td>0.19 - 1.00</td>
</tr>
<tr>
<td>Vertical Multiplier (VM)</td>
<td>0.89</td>
<td>0.07</td>
<td>0.63 - 1.00</td>
</tr>
<tr>
<td>Distance Multiplier (DM)</td>
<td>0.89</td>
<td>0.05</td>
<td>0.82 - 1.00</td>
</tr>
<tr>
<td>Asymmetric Multiplier (AM)</td>
<td>1.00</td>
<td>0.20</td>
<td>0.42 - 1.00</td>
</tr>
<tr>
<td>Frequency Multiplier (FM)</td>
<td>0.85</td>
<td>0.14</td>
<td>0.35 - 0.94</td>
</tr>
<tr>
<td>Coupling Multiplier (CM)</td>
<td>0.95</td>
<td>0.03</td>
<td>0.90 - 1.00</td>
</tr>
<tr>
<td><strong>Recommended Weight Limit (RWL)</strong></td>
<td><strong>15.96</strong></td>
<td><strong>7.13</strong></td>
<td><strong>2.84 - 33.36</strong></td>
</tr>
<tr>
<td><strong>Lifting Index (LI)</strong></td>
<td><strong>1.54</strong></td>
<td><strong>2.44</strong></td>
<td><strong>0.04 - 12.76</strong></td>
</tr>
</tbody>
</table>
# Recommended Weight of Limit (RWL) by Trade/Occupation (origin and destination)

<table>
<thead>
<tr>
<th>Trade/Occupation</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpenter (n=80)</td>
<td>17.8</td>
<td>8.2</td>
<td>33.0</td>
</tr>
<tr>
<td>Drop in Ceiling Installer (n=16)</td>
<td>8.0</td>
<td>4.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Dry Wall Installer (n=2)</td>
<td>26.4</td>
<td>24.7</td>
<td>28.0</td>
</tr>
<tr>
<td>Electrician (n=46)</td>
<td>16.4</td>
<td>6.5</td>
<td>31.5</td>
</tr>
<tr>
<td>Fitter (n=22)</td>
<td>17.2</td>
<td>7.9</td>
<td>29.9</td>
</tr>
<tr>
<td>Floor Finisher (n=12)</td>
<td>13.3</td>
<td>10.4</td>
<td>33.4</td>
</tr>
<tr>
<td>Floor Tile Layer (n=6)</td>
<td>16.0</td>
<td>10.1</td>
<td>29.4</td>
</tr>
<tr>
<td>Flooring Installer (n=12)</td>
<td>20.4</td>
<td>9.3</td>
<td>27.6</td>
</tr>
<tr>
<td>Insulator (n=14)</td>
<td>10.3</td>
<td>4.1</td>
<td>16.9</td>
</tr>
<tr>
<td>Laborer (n=14)</td>
<td>19.2</td>
<td>10.0</td>
<td>26.9</td>
</tr>
<tr>
<td>Mason (n=58)</td>
<td>13.9</td>
<td>2.8</td>
<td>32.2</td>
</tr>
<tr>
<td>Painter (n=2)</td>
<td>20.0</td>
<td>19.7</td>
<td>20.3</td>
</tr>
<tr>
<td>Plumber (n=2)</td>
<td>20.7</td>
<td>18.7</td>
<td>22.8</td>
</tr>
<tr>
<td>Sod Layer (n=6)</td>
<td>6.2</td>
<td>3.7</td>
<td>11.5</td>
</tr>
</tbody>
</table>
Lifting Index (LI) by Trade/Occupation

(origin and destination)
Results – Part II

Translating the Research Findings into the Actions
“Good Practices”
Results – Part II

Good Practices – Priority Basis

- Weight of Materials Lifted
- Horizontal Multiplier
- Frequency Multiplier
- Vertical Multiplier
- Asymmetric Multiplier

Weight of Materials – Highest Priority
Results – Part II

Good Practices
Manually Handling Materials, Tools, Equipment (MH-MTE)

- Purchase
  - MTE < 50 lbs
    - > 50 lbs – use handling aid, multiple workers
  - MTE < 10 inches center
    - 10” – 25” center - multiple workers, use handling aid

- Design Work Sites
  - Lifts in Mid Range of Body
  - Close – within 15”
  - Directly in front – no twisting
  - Below shoulder height

- Establish Work Rules & Train
  - Know weight of MTE – Label
  - Multiple worker policy

- MANUAL HANDLING MTE
  - Improving the Manual Handling of Materials, Tools and Equipment (MTE) on work sites can increase productivity by making manual tasks more efficient and may reduce worker injuries. Injuries from manual handling of MTE are the most frequent and costly type of worker injury in most industries. One or more of the following good practices will help achieve increased productivity and reduce the causes of worker injuries.
Results – Part II

Power Point Program
Manually Handling Materials, Tools, Equipment (MH-MTE)

Before Handling MTE
- Maintain Good Physical Condition
- Warm Up Muscles
- Stretch Ligaments
- Know its Weight
- Know when handling MTE
  - Needs Multiple Workers
  - Needs Handling Aid
  - Needs Mechanical Device
Borchardt (B) Factor concept definition:
- Weight (lbs or kg) per “easy to measure” unit of measurement such as weight per unit of area, length, brick, block, gallon or other “useful” measurements.

Examples:
- B(1/2” standard drywall) = 2.0 lbs per square foot
- B(5/8” “ “ “ ) = 2.5 “ “ “ “ “
- B(1/2 #4 rebar) = 0.668 lbs per linear foot
- B(2.25” #18 rebar) = 13.0 lbs per linear foot
Results – Part II
B Factor Application
Gypsum Board aka Drywall
Overexertion Highest Frequency – Lifting 55% (BLS 2009)

Weight per Unit Area
(for use in calculating dead loads)

Thickness Weight
in. (mm) psf kg/m²
1/4 (6.4 mm) 1.2 6.0
5/16 (7.9 mm) 1.3 6.4
3/8 (9.5 mm) 1.4 6.8
1/2 (12.7 mm) 2.0 9.8
5/8 (15.9 mm) 2.5 12
3/4 (19.0 mm) 3.0 15
1 (25.4 mm) 4.0 20

7. Handling and Storage
Handling Avoid contact with skin and eyes. Use only in well-ventilated areas. Handle and open container with care. Wear appropriate NIOSH approved dust mask or filtering facepiece if dust is generated. Do not eat or drink while using the product. Wash hands before eating, drinking, or smoking.
Results – Part II

B Factor Application
Rebar Table – Steel Linx Manufacture (Weight per Linear Foot)

<table>
<thead>
<tr>
<th>Rebar Rod Number</th>
<th>Rod Size (in)</th>
<th>Rod Weight (lb per linear foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.250 = 1/4</td>
<td>0.167</td>
</tr>
<tr>
<td>3</td>
<td>0.375 = 3/8</td>
<td>0.376</td>
</tr>
<tr>
<td>4</td>
<td>0.500 = 1/2</td>
<td>0.668</td>
</tr>
<tr>
<td>5</td>
<td>0.625 = 5/8</td>
<td>1.043</td>
</tr>
<tr>
<td>6</td>
<td>0.750 = 3/4</td>
<td>1.502</td>
</tr>
<tr>
<td>7</td>
<td>0.875 = 7/8</td>
<td>2.044</td>
</tr>
<tr>
<td>8</td>
<td>1.000</td>
<td>2.670</td>
</tr>
<tr>
<td>9</td>
<td>1.128</td>
<td>3.400</td>
</tr>
<tr>
<td>10</td>
<td>1.270</td>
<td>4.303</td>
</tr>
<tr>
<td>11</td>
<td>1.410</td>
<td>5.313</td>
</tr>
<tr>
<td>14</td>
<td>1.693</td>
<td>7.650</td>
</tr>
<tr>
<td>18</td>
<td>2.257</td>
<td>13.600</td>
</tr>
</tbody>
</table>
Results – Part II

B Factor Application
What Can Be Improved?

5/8” x 4' x 12' Gypsum Board aka Drywall

- B(5/8” Drywall) = 2.5 lbs/sf × 48 sf
- = 120 lbs
- Recommended Weight Limit (RWL) for Drywall = 28 lbs Max
- Lifting Index (LI) = 4.3
- Risk Factors?
  - Too heavy
- Improvements?
  - Use 2+ workers
  - Use mechanical handling aids
  - Use “25%” lighter weight drywall
Conclusions and Recommendations

- **SH&E Educators**
  - Improve Communication – NIOSH LE Components
  - Continue Research (PtRtP) e.g. RWL of Rebar, Lumber, Masonry Blocks, Bricks, etc.

- **SH&E Practitioners**
  - Short & Long Term Improvements – Manual Lifting Tasks
    - Purchase Lighter MTE - Reduce Weight
    - Move MTE Closer – Reduce Horizontal Distance
    - Add Workers – Reduce Frequency
    - Raise MTE– Reduce Vertical Bending
    - Raise Workers – Reduce Overhead Reaching
    - Change MTE Packaging – Handles Improve Coupling

- **SH&E Educators & Practitioners**
  - Know/Modify Weight of MTE & Lifting Task Variables
Questions