Lifting Hazards

Manual Materials Handling

Using the Liberty Mutual tables to evaluate these tasks

By Patrick G. Dempsey and Wayne S. Maynard

MANUAL MATERIALS HANDLING (MMH) tasks (pushing, pulling, lifting, lowering and carrying) are the leading source of workers' compensation claims (Dempsey and Hashemi). MMH remains a common exposure in many industry sectors including manufacturing and service occupations. The most effective means of minimizing risk is through the application of engineering controls—either removing the exposure through automation or reducing it through ergonomic design or mechanization. The specific tasks, machines and/or equipment to be modified are often selected based on the results of a detailed ergonomic analysis.

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Fewer workers now perform a single task or a few tasks repetitively, as many of these jobs have been automated. As a result, the SH&E professional must assess a wide range of tasks required by a job, particularly in the service industry where jobs are characterized by variable demands. Although both types of jobs require frequent, repetitive handling, the latter is characterized by more variability in task parameters such as load and lift distance. Ergonomic assessments of these jobs provide valuable information for job design and redesign decisions.

Physical loading posed by MMH is assessed using different design criteria, such as spinal compression (biomechanical approach), oxygen consumption (physiological approach) and the percentage of the population that finds a task acceptable with respect to fatigue and stress (psychophysical approach). Manual handling criteria are usually applied through observational methods. The analyst first separates a job into distinct tasks, then measures the parameters of the tasks. The parameters are then used to estimate stress posed by the tasks.

Many of these methods can be applied using a tape measure, protractor and watch. Examples of parameters measured include joint angles, task frequency, lift distance and object weight. Video analysis is helpful or required for some analyses, particularly for biomechanical assessments.

Before job design and redesign decisions are implemented, an understanding of MMH risk factors and acceptable workloads is recommended. Risk factors associated with lifting, lowering, pushing, pulling and carrying tasks or associated with the work environment include:

- excessive weights and forces;
- undesirable postures such as bending, reaching and twisting;
- slips and falls due to environmental hazards while handling materials;
- prolonged sitting;
- whole-body vibration.

Selection of a particular analytical method is driven by the SH&E professional's preference and by which method is most appropriate. For lifting and lowering tasks, Figure 1 shows a graphical representation of the influence of task frequency on the choice of tool, where darker shading indicates higher relevance. This was derived from work based on a comprehensive review of the literature (Dempsey). Biomechanics is best for analyzing high-load, low-frequency exposures, whereas the physiologic approach is intended for high-frequency tasks. Psychophysics is best for intermediate frequencies. Additionally, the most important practical aspects of selecting a method, such as expertise and cost, are shown in Table 1.

Of the methods listed in Table 1, the psychophysical approach is applicable to the widest range of tasks, in part because of the large databases available. Psychophysical tables are among the easiest MMH assessment methods to use, and the tables published by Snook and Ciriello are the most comprehensive in terms of the range of task parameters covered, types of tasks (lifting, lowering, pushing, pulling and carrying) and the number of subjects used to develop the database (Snook and Ciriello; see Mital, et al for additional tables).

Abstract: *Several approaches to control of overexertion associated with manual materials handling have been developed and researched. Many researchers have used the psychophysical approach to develop extensive tables of guidelines for assessing pushing, pulling, lifting, lowering and carrying tasks. This article describes the application of a modification of the Snook and Ciriello tables that makes them easier to use and interpret. Use of the tables to assess tasks is described, and examples—including how to use the tables to perform "what-if" analyses of redesign recommendations—are discussed as well.*

Liberty Mutual Tables

Since the late 1970s, Liberty Mutual Group has been analyzing and evaluating lifting, lowering, pushing, pulling and carrying tasks using psychophysical tables (hereafter referred to as "tables") developed with the psychophysical approach. This approach specifies a response to subjects performing MMH tasks through instructions (e.g., do not become unusually tired, weakened, overheated or out of breath), and subjects adjust the load handled or push/pull forces (called the stimulus) until they feel they are working at the response specified in the instructions. Further details of the experimental designs are found in the individual papers [e.g., Ciriello and Snook; Ciriello, et al(b); Ciriello, et al(a)].

The tables used by Liberty Mutual were much different from those in the published literature. Some have referred to those in the published literature as "Snook Tables" (Snook) and later "Snook and Ciriello Tables" (Snook and Ciriello).

The published tables were redesigned for easier use in the field. Designed for loss prevention consultants, the tables provide the male and female population percentages able to perform these tasks, while the published journal articles provided maximum acceptable weights and forces for 10, 25, 50, 75 and 90 percent of the male and female population. The redesigned tables are called "Liberty Mutual Tables" and were later developed into an ergonomic software analysis program (CompuTask™) to facilitate data analysis and the interpolations that may be required.

The tables were developed with the goal of controlling losses associated with injuries attributed to manual handling operations. These losses are primarily due to costly low-back disability claims and reduced productivity and quality caused by poor job design. The tables provide the user with an objective risk assessment of a problem manual handling job and the foundation on which to build a solution to help users:

1) recognize risk factors associated with manual handling activity;

2) make good business decisions on implementing cost-effective ergonomic solutions that maximize the percentage of the population capable of performing tasks.

Using these tables effectively requires training in ergonomics and manual handling task analysis and evaluation. Users should also be knowledgeable of the basic biomechanical and physiological workload criteria and evaluation methods. Although psychophysical tables are easy to use, knowledge of the effects of high biomechanical and physiological loads caused by materials handling is important. Training should also include guidance on how to develop an analysis strategy, and the collection of basic measurements including weights, initial and sustained forces, distances (lifting, lowering, carrying, hand distance from body) and task frequency.

Generally, designing manual tasks for greater than 75 percent of the female work population will offer the best protection against manual handling injuries. Studies have shown that two-thirds of low-back claims from low-percentage tasks (can be performed by a small percentage of the population) can be prevented if the tasks are designed to accommodate at least 75 percent of the female work population (Snook). Tasks with population percentages of less than 10 percent should be a high priority for redesign.

ANSI B11 TR.1-2004 contains the following tables:

1) Population percentages for lifting tasks ending (female, male):
- below knuckle height (<28 inches; <31 inches);
- between knuckle height and shoulder height (≥28 inches and ≤53 inches; ≥31 inches and ≤57 inches);
- above shoulder height (>53 inches; >57 inches).

2) Population percentages for lowering tasks beginning (female, male):
- below knuckle height (<28 inches; <31 inches);
- between knuckle height and shoulder height (≥28 inches and ≤53 inches; ≥31 inches and ≤57 inches);
- above shoulder height (>53 inches; >57 inches).

3) Female and male population percentages for pushing tasks:
- initial forces;
- sustained forces.

4) Female and male population percentages for pulling tasks:
- initial force;
- sustained forces.

5) Female and male population percentages for carrying tasks.

Figure 1

Selecting a Method: Tradeoffs

Overview of tradeoffs when selecting a manual materials handling measurement and evaluation method (darker shading indicates higher relevance).

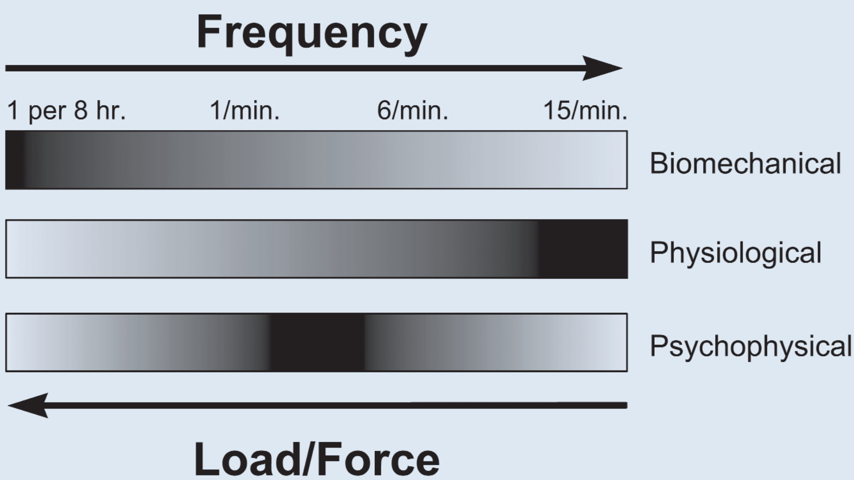


Table 1

Overview of Major Manual Materials Handling Assessment Methods

Assessment Method	Major Advantages	Major Disadvantages
Biomechanical Model	1) Appropriate for jobs requiring high forces, handling of heavy loads. 2) Quantitative. 3) Covers lifting, lowering, pushing and pulling.	1) Practicality limits application to static analyses in the workplace—this may underestimate stress and limit scope of job that can be analyzed. 2) Fairly expensive (if software is purchased). 3) High expertise required. 4) Carrying is excluded.
Psychophysical Tables	1) Easy to use. 2) Inexpensive. 3) Cover lifting, lowering, pushing, pulling and carrying. 4) Extensive data available. 5) Can be used for nonstandard MMH tasks (e.g., mining).	1) May ignore high biomechanical and physiological demands. 2) Based on subjective responses.
Physiological Approach (energy expenditure models)	1) Appropriate for high frequency tasks. 2) Usually the only practical method of assessing energy expenditure.	1) Accuracy of available models is variable (i.e., large errors are possible). 2) Relationship between energy expenditure and health effects has not been demonstrated.

Examples & Use of the Tables

Following are two examples that illustrate how the tables can be used to analyze a lifting task, as well as to estimate the improvement which a given engineering control will provide.

Example 1

A manufacturing job requires assembled parts to be placed in a tote pan and lifted to various heights of a cart, the highest of which is 50 inches above the ground. Measurements indicate:
- Tote pan weighs 29 pounds (object weight).
- Hand distance is seven inches (hand distance away from body).

•The initial hand height is 30 inches (hand height at start).

•The final hand height is 50 inches (hand height at end).

•Pans are lifted once every five minutes (task frequency).

•The task is performed by males and females.

Table 2 presents Liberty Mutual's Table 2F, the correct table for a lifting task ending between knuckle and shoulder height (≥28 inches and ≤53 inches), and for a female population.

Using the object weight of 29 pounds to select the row and hand distance of seven inches to select the column, the large shaded cell in Table 2 is the correct area of the table. Given a lifting distance of 20 inches and a frequency of once every five minutes, the table indicates that this task is acceptable to 60 percent of the female work population. Since a goal should be to accommodate at least 75 percent of that population—and preferably 90 percent or more—this task should be modified to accommodate a higher percentage of the population.

Since measurements seldom correspond exactly to the data points used in the tables, it may be necessary to estimate the population percentage. For ex-

Table 2

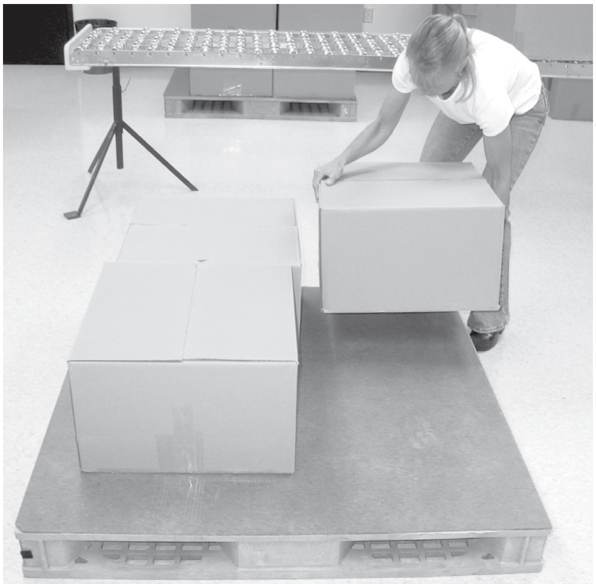
Liberty Mutual's Table 2F for Female Population Lifting Tasks

This table is for lifting tasks ending between knuckle height and shoulder height (≥28 inches and ≤53 inches). The light shaded area is for the first example, the darker shaded area is for the what-if scenarios.

Hand Distance		7 inches					10 inches					15 inches				
Frequency One Lift Every		15s	30s	1m	5m	8h	15s	30s	1m	5m	8h	15s	30s	1m	5m	8h
Object Weight (pounds)	Lifting Distance (inches)															
59	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	30	-	-	-	-	-		-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	15	-	-	-	-	-	-	-	-	-	-
53	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	21	-	-	-	-	-	-	-	-	-	-
50	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	29	-	-	-	-	14	-	-	-	-	-
47	30	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	24	-	-	-	-	11	-	-	-	-	-
	10	-	-	-	-	38	-	-	-	-	21	-	-	-	-	-
44	30	-	-	-	-	19	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	34	-	-	-	-	17	-	-	-	-	-
	10	-	-	-	15	48	-	-	-	-	30	-	-	-	-	-
41	30	-	-	-	-	29	-	-	-	-	14	-	-	-	-	-
	20		-	-	12	44	-	-	-	-	26	-	-	-	-	-
	10	-	-	14	23	58	-	-	-	-	41	-	-	-	-	-
38	30	-	-	-	-	40	-	-	-	-	22	-	-	-	-	-
	20	-	-	12	21	56	-	-	-	-	38	-	-	-	-	-
	10	-	-	23	34	68	-	-	-	18	52	-	-	-	-	17
35	30	-	-	-	18	52	-	-	-	-	34	-	-	-	-	-
	20	-	14	22	32	66	-	-	-	16	50	-	-	-	-	16
	10	11	18	35	47	76	-	-	18	29	63	-	-	-	-	28
32	30	-	-	20	30	64	-	-	-	15	48	-	-	-	-	14
	20	20	25	34	46	76	-	11	18	28	62	-	-	-	-	28
	10	20	30	49	60	83	-	14	31	42	73	-	-	-	11	42
29	30	12	18	33	45	75	-	-	17	27	61	-	-	-	-	27
	20	34	39	49	60	83	18	22	31	43	74	-	-	-	11	42
	10	34	45	62	71	89	18	27	45	56	82	-	-	13	22	56
26	30	25	33	50	60	84	11	17	32	43	74	-	-	-	11	43
	20	50	55	64	73	89	32	38	47	58	83	-	-	14	23	58
	10	50	60	75	81	+	33	43	61	70	88	-	12	26	37	70
23	30	43	52	66	74	+	25	34	50	61	84	-	-	16	26	60
	20	66	70	77	83	+	51	56	64	73	89	17	21	30	41	73
	10	67	74	84	88	+	51	61	75	81	+	18	26	44	55	81
20	30	62	70	80	85	+	46	54	68	76	+	14	20	35	46	76
	20	80	83	87	+	+	69	73	79	84	+	37	41	51	61	84
	10	80	85	+	+	+	69	76	85	89	+	37	47	64	72	89
17	30	79	84	+	+	+	68	74	83	88	+	35	44	59	68	87
	20	+	+	+	+	+	83	86	89	+	+	60	64	71	79	+
	10	+	+	+	+	+	84	88	+	+	+	61	69	80	85	+
14	30	+	+	+	+	+	85	88	+	+	+	63	70	80	85	+
	20	+	+	+	+	+	+	+	+	+	+	80	83	87	+	+
	10	+	+	+	+	+	+	+	+	+	+	81	85	+	+	+
11	30	+	+	+	+	+	+	+	+	+	+	85	88	+	+	+
	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8	30	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Note: + = greater than 90 percent; - = less than 10 percent

Source: Liberty Mutual. Tables are available from the Liberty Mutual Research Institute for Safety website at http://libertymmhtables.libertymutual.com/CM_LMTablesWeb/taskSelection.do?action=initTaskSelection.



Origin (Photo 1, right) and destination (Photo 2, below) of lifting task for first layer of palletizing operation.

ample, if the object weighed 30 pounds, it would fall between the 29-pound cell and the 32-pound cell. Linear interpolation gives a population percentage of 55.

Example 2: "What-If" Analysis

Since it can be difficult to design jobs that can be performed by 75 percent of the female work population, the tables are often used to perform what-if scenarios of various ergonomic interventions to help determine the most cost-effective and practical solution which offers the highest degree of control. Photos 1 and 2 illustrate the origin and destination for a lifting task involved in the first layer of a depalletizing task, respectively. Pallet height is five inches, and the height of the conveyor on which boxes are placed is 30 inches, which results in a lift distance of 25 inches. Boxes weigh 20 pounds; on average, two boxes are palletized per minute (or a frequency of one box/30 seconds).

The box is 20 inches across, so hand distance would be about 10 inches if the box can be handled close to the body. Due to the reaching involved on the lower layer of the pallet, however, hand distances are about 15 inches. Since both females and males perform the job, this task will be analyzed using the female population percentages.

To analyze the task, first locate the 20-pound object weight in Table 2 and move to the far right-hand distance column for the 15-inch hand distance. Select the 30-second frequency column. Since the lift distance is 25 inches, linear interpolation between the population percentages of 20 percent and 41 percent gives a result of 30 percent of the female population being accommodated. This task is a candidate for redesign, especially since the risk factors of bending, reaching and twisting are present as well.

An effective means of reducing exposure to the risk factors and stress from a depalletizing operation such as this is to install a scissor-lift table. The lift can be adjusted so that minimal bending is required for each layer, thus effectively decreasing or eliminating a lift distance. If the table also rotates, this can reduce the need for lifting while reaching as the boxes can be kept close to the body. Furthermore, twisting can be reduced since the table can be rotated rather than the spine.

A what-if analysis can be performed assuming installation of the lift table. Although the object weight and frequency remain the same, the lift distance is essentially eliminated; therefore, the 10-inch lift distance row can be used. Also, since the boxes can now be lifted close to the body, the hand distance is reduced from 15 inches to 10 inches—or half the box width. The population percentage of 76 percent shown in Table 2 corresponding to these parameter values indicates a considerably better situation. Bending, reaching and some twisting would likely be eliminated as well. These results can then be used to justify the installation of a lift table. If the lift table is deemed too expensive, less-expensive controls such as increasing the height of the pallet (e.g., by stacking empty pallets), limiting the height that boxes are stacked on the pallet or reducing the frequency or weights of the boxes.

One dimension that is occasionally confusing when analyzing lifting and lowering tasks is hand distance. Hand distance is the distance from the front of the body to the hands. Note that this is a different measurement from that used for the NIOSH equation which measures the distance from the midpoint between the ankles to the hands (Waters, et al). Hand distance is normally half the width of the object being handled unless the object is deliberately held away from the body or if reaching is required.

For pushing and pulling tasks, one must obtain a spring scale, a load cell or other force measurement device and enter the initial force, in pounds, needed to start the object moving. Take several measurements and enter the highest value—particularly when floor or wheel conditions are poor. For pushing tasks, a spring-scale device can be used to measure the force by pulling if an appropriate gauge is not available. While the effect on the worker may be different between a push and pull, the measured force will be the same. One must also determine the sustained force measurement needed to keep the object moving. All measurements should be taken at a pace representative of the task as it is actually performed. The average sustained force from several trials can be used to find the appropriate population percentage. The distance the cart is pushed is also required.

Carrying tasks are straightforward to analyze. Like all types of tasks, frequency is required. Like lifting and lowering, the object weight is required. Similarly, hand height and carry distance are analogous to the measures taken for pushing and pulling.

Frequency can be confusing when more than one task component is present (e.g., lifting an object, carrying it a distance and putting it back down. Frequency is defined as the average time between handling individual objects. In Example 2, if objects are lifted, carried and lowered within a job cycle time of 30 seconds, the frequency would be 30 seconds for the lift, 30 seconds for the carry and 30 seconds for the lowering.

A Word of Caution

Tasks should not be evaluated based solely on population percentages or on the results of any single analysis approach. Other important considerations include:

• **Injuries.** Any job that results in injuries is a good candidate for redesign.

• **Bending.** Any task that begins or ends with the hands below knuckle height presents some degree of risk. The deeper the bending motion, the greater the physical stress on the low back. Frequent bending regardless of weight is not recommended.

• **Twisting.** This motion puts uneven forces on the back thereby presenting additional physical stress. The greater the twist, the more physically stressful the task.

• **Reaching.** The distance away from the body that a load is held greatly affects the forces on the back, shoulders and arms. The farther the reach, the more physically stressful the task since the moment (load weight times reach distance) created is increased, thus producing higher spinal stress.

• **One-handed lifts.** The tables cannot be used to evaluate one-handed tasks. By nature, these tasks place uneven loads on the back and present a greater physical stress than two-handed lifts.

• **Hand-holds.** Inability to get a good grip on the load presents a greater physical stress.

• **Catching or throwing items.** The tables cannot be used to evaluate these types of tasks. Any task that involves catching or throwing items is physically stressful and, therefore, is a candidate for redesign.

The population percentages in these tables are based on weights selected by subjects in the laboratory working as hard as possible without straining themselves, or without becoming unusually tired, weakened, overheated or out of breath. Jobs designed ergonomically should fit most workers, which is why 75 percent of the female work population is selected as a design starting point. Population percentages in these tables should not be used to determine whether male or female workers can perform certain jobs to place workers.

These tables should be used only for designing manual handling jobs with physical requirements so that as many workers as possible can perform them without risk of injury. As noted, one must be trained in ergonomics and task evaluation methods in order to properly apply these tables, interpret results and develop effective solutions. Whether a workload is "acceptable" depends not only on the task itself, but also on the presence of other potential risk factors. Low-back pain is a complex phenomenon and requires a comprehensive approach to control. For example, while a 20-pound infrequent lift may seem like light work, frequent bending, reaching and twisting place additional stress on the spine. Similarly, whole-body vibration exposure could increase risk.

Conclusion

The Liberty Mutual tables are an effective tool for assessing MMH demands. They have been widely used, either in the original form (Snook and Ciriello) or in the form discussed here. The data were used in the development of the revised NIOSH lifting equation (Waters, et al) and more recently by ANSI. As with any MMH assessment tool, these tables should be viewed as one tool of several. Biomechanical assessment may be required for high-force tasks, and physiological assessment may be required for tasks that require high rates of energy consumption. ■

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