Ergonomics, manual handling, lifting limitation, recommended weight limit.

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SAFE MANUAL HANDLING IN INDUSTRIAL PRODUCTION

Abstract

This section provides the technical information for using the revised lifting equation to evaluate a variety of two-handed manual lifting tasks. Definitions, restrictions/limitations, and data requirements for the revised lifting equation are also provided.

INTRODUCTION

Everyday manual handling with objects of certain weight is characteristic of a large number of work activities. Many times we do not perceive that such work could lead to the risk of health problems. Each of activities as a lifting, handling, placing or holding objects in the certain position are regarded as manual handling with loads.

For the manual handling with loading we could consider the following situations:

- Handling with change parts of machine such as driver and fixing devices, preparation and etc., that operator with regard to technological procedures removing, fixing or setting up with them machine or other processing equipments,
- Handling with work-pieces, components, semi-products, products, materials and etc. that operator puts or grips into machine or that operator takes from the machine after finishing technological operation and puts them on determinate place,
- Handling with containers, pallets and etc. that contain components, work-pieces, elements and etc., that are intended to transport through the use of chosen conveyor.
- Handling with packages, boxes and etc., that contain various objects that are removed and subsequently stored in solid racks or mobile racks in the storehouses,
- Handling with elements, components and etc. that operator takes away from pallets, stock bins and subsequently their assembles and sets up them either on work table or flow production,
- Handling with building and assembly components, prefabricated elements and etc. , that operator replaces straight or in various heights,

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- Handling with free stored loose materials, that operator removes through the use of handling tools or packaging,
- Handling with cans or bottles containing liquid, gas or other materials,

If we will not concentrate on industrial production only we would be able to identify the large number of cases that could be regarded as handling with loading. Example could be handling with immobile patient that presents work with specific load.

There are seven factors to having influence on work with loads:
1. Loading and his properties,
2. Way of handling,
3. Working position and movement,
4. Tools and facilities for light handling,
5. Workplace, working station and working environment,
6. Loading risk,
7. Individual factors of handler,

The Slovak industrial practice uses specific rules regulating the handling with loads. Expect of governmental notes and rules there are interplant instructions, ergonomics catalogues and etc. In the Slovak practice we are missing instrument documenting the above mentioned factors and result of which would be description of ergonomics capacity of handling. In the Europe successfully has been applying index NIOSH for many years which it is regard as standard of handling with loads. An effort of Department of Industrial Engineering with cooperation of Slovak Productivity Center is introduce active applying of this index to work of ergonomist as a separate instrument or as a part of complex ergonomics result within the frame of Digital Factory.

1. PHYSICAL LOADING CLASSIFICATION SINGLE TASK, PERFORMED REPETITIVELY

The job illustrated in Figure 1 consists of a worker assembling gearbox. He must lift gearbox one and plant on gearbox two. Duration of this activity is 5 seconds and he do it at rate 0,5/min. The gear-box is not of optimal design, and without handles. We need answer, if weight of gearbox is greater than recommended weight limit.

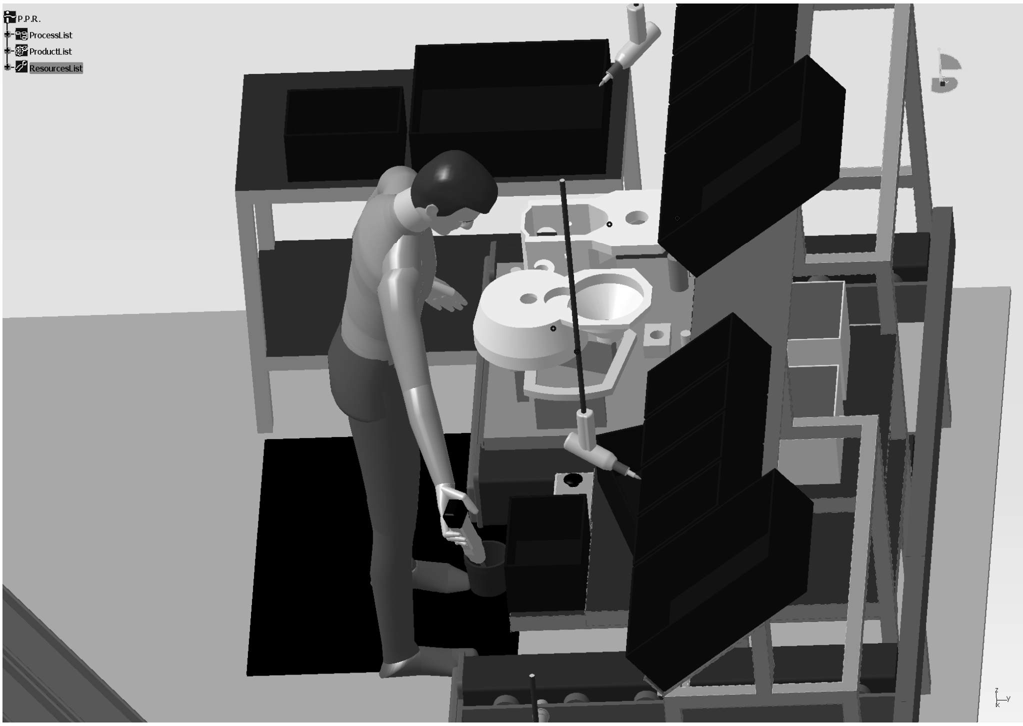

Fig. 1 Gear-box assembly

The Revised NIOSH Lifting Equation and Lifting Index will be applied for design of lifting gearbox.

2. RECOMMENDED WEIGHT LIMIT (RWL)

The RWL is the principal product of the revised NIOSH lifting equation. The RWL is defined for a specific set of task conditions as the weight of the load that nearly all healthy workers could perform over a substantial period of time (e.g., up to 8 hours) without an increased risk of developing lifting-related LBP. By healthy workers, we mean workers who are free of adverse health conditions that would increase their risk of musculoskeletal injury.

2.1 Lifting Task Limitations

The lifting equation is a tool for assessing the physical stress of two-handed manual lifting tasks. As with any tool, its application is limited to those conditions for which it was designed. Specifically, the lifting equation was designed to meet specific lifting-related criteria that encompass biomechanical, work physiology, and psychophysical assumptions and data, identified above. To the extent that a given lifting task accurately reflects these underlying conditions and criteria, this lifting equation may be appropriately applied.

The Revised NIOSH Lifting Equation does not apply if any of the following occur:

- Lifting / lowering with one hand.
- Lifting / lowering for over 8 hours.
- Lifting / lowering while seated or kneeling.
- Lifting / lowering in a restricted work space.
- Lifting / lowering unstable objects.
- Lifting / lowering while carrying, pushing or pulling.
- Lifting / lowering with wheelbarrows or shovels.
- Lifting / lowering with high speed motion (faster than about 30 inches/second).
- Lifting / lowering with unreasonable foot/floor coupling (< 0,4 coefficient of friction between the sole and the floor).
- Lifting / lowering in an unfavorable environment (i.e., temperature significantly outside 19-26°C range; relative humidity outside 35-50% range).

For those lifting tasks in which the application of the revised lifting equation is not appropriate, a more comprehensive ergonomic evaluation may be needed to quantify the extent of other physical stressors, such as prolonged or frequent non-neutral back postures or seated postures, cyclic loading (whole body vibration), or unfavorable environmental factors (e.g., extreme heat, cold, humidity, etc.).

The revised lifting equation for calculating the Recommended Weight Limit (RWL) is based on a multiplicative model that provides a weighting for each of six task variables. The weightings are expressed as coefficients that serve to decrease the load constant, which represents the maximum recommended load weight to be lifted under ideal conditions. The RWL is defined by the following equation:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \qquad (1)$$

Where:

LC	- Load Constant	= 23 kg (Central Europe)	(2)
HM	- Horizontal Multiplier	$= (25/H)$	(3)
VM	- Vertical Multiplier	$= 1-0{,}003 \cdot \lvert V-75 \rvert$	(4)
DM	- Distance Multiplier	$= 0{,}82 + (4{,}5/D)$	(5)
AM	- Asymetric Multiplier	$= 1-(0{,}0032 \cdot A)$	(6)
FM	- Frequency Multiplier	Table 5	(7)
CM	- Coupling Multiplier	Table 6	(8)

The term task variables refers to the measurable task descriptors (i.e., H, V, D, A, F, and C); whereas, the term multipliers refers to the reduction coefficients in the equation (i.e., HM, VM, DM, AM, FM, and CM).

Each multiplier should be computed from the appropriate formula, but in some cases it will be necessary to use linear interpolation to determine the value of a multiplier, especially when the value of a variable is not directly available from a table. For example, when the measured frequency is not a whole number, the appropriate multiplier must be interpolated between the frequency values in the table for the two values that are closest to the actual frequency.

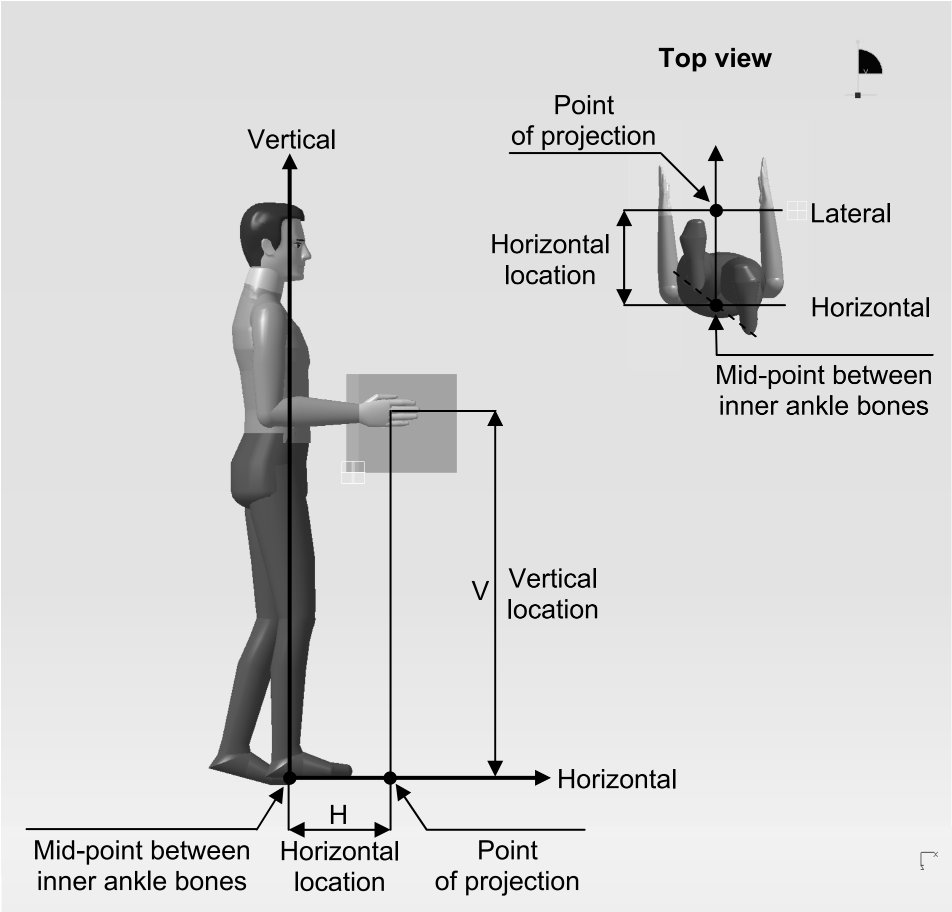

Fig. 2 Graphic Representation of Hand Location

Horizontal Component

Horizontal Location (H) is measured from the mid-point of the line joining the inner ankle bones to a point projected on the floor directly below the mid-point of the hand grasps (i.e., load center), as defined by the large middle knuckle of the hand Figure 2.

The Horizontal Multiplier (HM) is:

$$HM = 25/H \quad (3)$$

for H measured in centimeters. If H is less than or equal to 25 cm, then the multiplier is 1.0. HM decreases with an increase in H value. The multiplier for H is reduced to 0,4 when H is 63 cm. If H is greater than 63 cm, then HM = 0. The HM value can be computed directly or determined from Table 1.

Table 1

H [cm]	HM	H [cm]	HM	H [cm]	HM
≤25	1,00	40	0,63	54	0,46
28	0,89	42	0,60	56	0,45
30	0,83	44	0,57	58	0,43
32	0,78	46	0,54	60	0,42
34	0,74	48	0,52	63	0,40
36	0,69	50	0,50	>63	0,00
38	0,66	52	0,48		

Vertical component

Vertical Location (V) is defined as the vertical height of the hands above the floor. V is measured vertically from the floor to the mid-point between the hand grasps, as defined by the large middle knuckle. The coordinate system is illustrated in Figure 2.

The vertical location (V) is limited by the floor surface and the upper limit of vertical reach for lifting (i.e., 175 cm). The vertical location should be measured at the origin and the destination of the lift to determine the travel distance (D).

To determine the ***Vertical Multiplier (VM)***, the absolute value or deviation of V from an optimum height of 75 cm is calculated. A height of 75 cm above floor level is considered "knuckle height" for a worker of average height (165 cm). The Vertical Multiplier (VM) is:

$$VM = 1\text{-}0{,}003\,|V\text{-}75| \qquad (4)$$

for V measured in centimeters.

When V is at 75 cm, the vertical multiplier (VM) is 1.0. The value of VM decreases linearly with an increase or decrease in height from this position. At floor level, VM is 0.78, and at 175 cm height VM is 0.7. If V is greater than 175 cm, then VM = 0. The VM value can be computed directly or determined from Table 2.

Table 2

V [cm]	VM	V[cm]	VM	V [cm]	VM
0	0,78	70	0,99	140	0,81
10	0,81	80	0,99	150	0,78
20	0,84	90	0,96	160	0,75
30	0,87	100	0,93	170	0,72
40	0,90	110	0,90	175	0,70
50	0,93	120	0,87	>175	0,00
60	0,96	130	0,84		

Distance component

The ***Vertical Travel Distance variable (D)*** is defined as the vertical travel distance of the hands between the origin and destination of the lift. For lifting, D can be computed by subtracting the vertical location (V) at the origin of the lift from the corresponding V at the destination of the lift (i.e., D is equal to V at the destination minus V at the origin). For a lowering task, D is equal to V at the origin minus V at the destination.

$$D = V_O - V_D \qquad (9)$$

for $25 \leq D \leq 175$

If the vertical travel distance is less than 25 cm, then D should be set to the minimum distance of 25 cm.

The Distance Multiplier (DM) is:

$$DM = 0{,}82 + (4{,}5/D) \qquad (5)$$

for D measured in centimeters. For D less than 25 cm D is assumed to be 25 cm, and DM is 1.0. The Distance Multiplier, therefore, decreases gradually with an increase in travel distance. The DM is 1.0 when D is set at 25 cm; DM is 0.85 when D = 175 cm. Thus, DM ranges from 1.0 to 0.85 as the D varies from 0 cm to 175 cm. The DM value can be computed directly or determined from Table 3.

Table 3

D [cm]	DM	D [cm]	DM	D [cm]	DM
≤ 25	1,00	85	0,87	145	0,85
40	0,93	100	0,87	160	0,85
55	0,90	115	0,86	175	0,85
70	0,88	130	0,86	>175	0,00

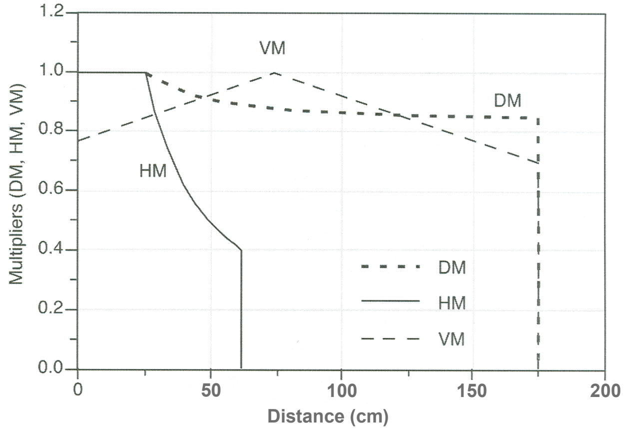

Fig. 3 Multipliers for HM, VM a DM

Asymmetry Component

The asymmetric angle (A) is operationally defined as the angle between the asymmetry line and the mid-sagittal line. The asymmetry line is defined as the horizontal line that joins the mid-point between the inner ankle bones and the point projected on the floor directly below the mid-point of the hand grasps, as defined by the large middle knuckle.

The angle A is limited to the range from 0 degrees to 135 degrees. If A > 135 degrees, then AM is set equal to zero, which results in a RWL of zero, or no load.

The Asymmetric Multiplier (AM)

$$AM = 1 - 0{,}0032 \cdot A \qquad (6)$$

The AM has a maximum value of 1.0 when the load is lifted directly in front of the body. The AM decreases linearly as the angle of asymmetry (A) increases. The range is from a value of 0.57 at 135 degrees of asymmetry to a value of 1.0 at 0 degrees of asymmetry (i.e., symmetric lift).

If A is greater than 135 degrees, then AM = 0, and the load is zero. The AM value can be computed directly or determined from Table 4.

Table 4

A [deg]	**AM**	**A [deg]**	**AM**	**A [deg]**	**AM**
0	1,00	60	0,81	130	0,62
15	0,95	75	0,76	135	0,57
30	0,90	90	0,71	>135	0,00
45	0,86	105	0,66		

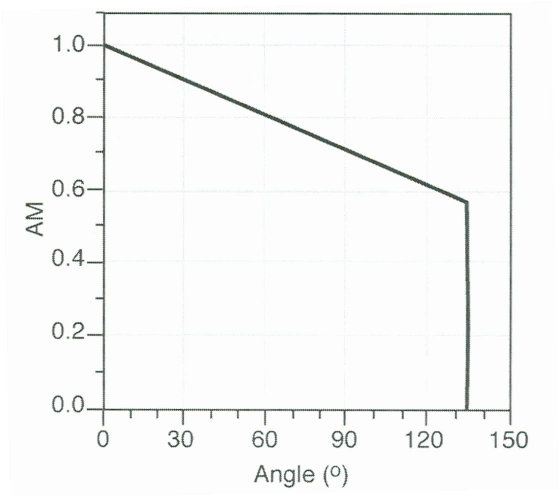

Fig. 4 Asymetry Multiplier

Frequency component

The ***frequency multiplier*** is defined by (a) the number of lifts per minute (frequency), (b) the amount of time engaged in the lifting activity (duration), and (c) the vertical height of the lift from the floor. Lifting frequency (F) refers to the average number of lifts made per minute, as measured over a 15-minute period. Because of the potential variation in work patterns, analysts may have difficulty obtaining an accurate or representative 15-minute work sample for computing the lifting frequency (F). If significant variation exists in the frequency of lifting over the course of the day, analysts should employ standard work sampling techniques to obtain a representative work sample for determining the number of lifts per minute. For those jobs where the frequency varies from session to session, each session should be analyzed separately, but the overall work pattern must still be considered. For more information, most standard industrial engineering or ergonomics texts provide guidance for establishing a representative job sampling strategy (e.g., Eastman Kodak Company, 1986).

Lifting frequency (F) for repetitive lifting may range from 0.2 lifts/min to a maximum frequency that is dependent on the vertical location of the object (V) and the duration of lifting Table 5. Lifting above the maximum frequency results in a RWL of 0.0. (Except for the special case of discontinuous lifting discussed above, where the maximum frequency is 15 lifts/minute.)

Table 5

Frequency Lifts/min	**Work Duration [hrs]**					
	< 1		**< 2**		**≤ 8**	
	V < 75	**V > 75**	**V < 75**	**V > 75**	**V < 75**	**V > 75**
≤ 0,2	1,00	1,00	0,95	0,95	0,85	0,85
0,5	0,97	0,97	0,92	0,92	0,81	0,81
1	0,94	0,94	0,88	0,88	0,75	0,75
2	0,91	0,91	0,84	0,84	0,65	0,65
3	0,88	0,88	0,79	0,79	0,55	0,55
4	0,84	0,84	0,72	0,72	0,45	0,45
5	0,80	0,80	0,60	0,60	0,35	0,35
6	0,75	0,75	0,50	0,50	0,27	0,27
7	0,70	0,70	0,42	0,42	0,22	0,22
8	0,60	0,60	0,35	0,35	0,18	0,18
9	0,52	0,52	0,30	0,30	0,00	0,15
10	0,45	0,45	0,26	0,26	0,00	0,13
11	0,41	0,41	0,00	0,23	0,00	0,00
12	0,37	0,37	0,00	0,21	0,00	0,00
13	0,00	0,34	0,00	0,00	0,00	0,00
14	0,00	0,31	0,00	0,00	0,00	0,00
15	0,00	0,28	0,00	0,00	0,00	0,00
≥15	0,00	0,00	0,00	0,00	0,00	0,00

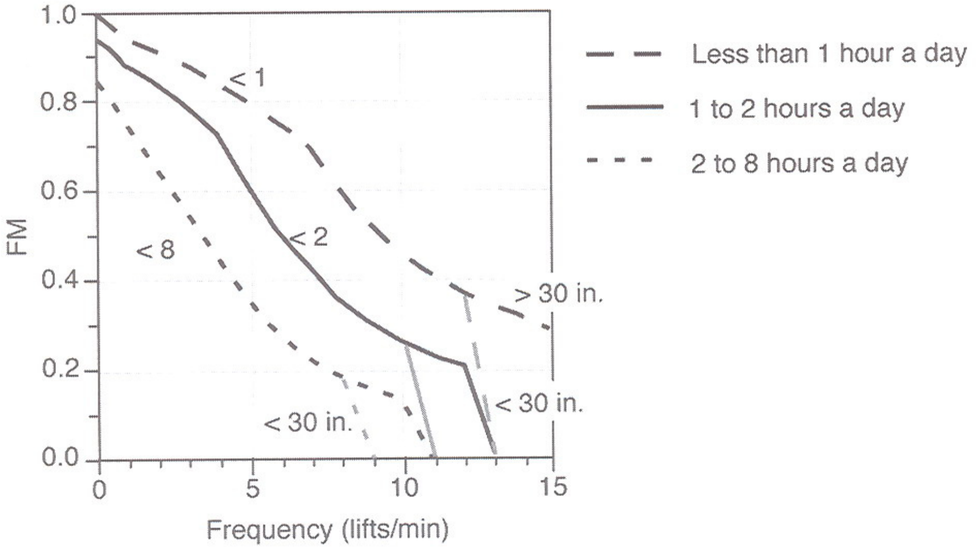

Fig. 5 Frequency Mulipliers

Coupling component

The nature of the hand-to-object ***coupling*** or gripping method can affect not only the maximum force a worker can or must exert on the object, but also the vertical location of the hands during the lift. A good coupling will reduce the maximum grasp forces required and increase the acceptable weight for lifting, while a poor coupling will generally require higher maximum grasp forces and decrease the acceptable weight for lifting.

The effectiveness of the coupling is not static, but may vary with the distance of the object from the ground, so that a good coupling could become a poor coupling during a single lift. The entire range of the lift should be considered when classifying hand-to-object couplings, with classification based on overall effectiveness. The analyst must classify the coupling as good, fair, or poor. The three categories are defined in Table 6. If there is any doubt about classifying a particular coupling design, the more stressful classification should be selected.

Table 6

GOOD	FAIR	POOR
For containers of optimal design such as some boxes crates, etc., a "Good" hand-to object coupling would be defined as handles or hand-hold cut-outs of optimal design (see notes 1 to 3 below)	For containers of optimal design, a "Fair" hand-to-object coupling would be defined as handles or hand-hold cut-outs of less than optimal design (see notes 1 to 4) below.	Containers of less than optimal design or loose parts or irregular objects that are bulky hard to handle, or have sharp edges (see notes below).

For loose parts or irregular objects, whoch are not usually containerized, such as castings, stock, and supply materials, a “Good” hand-to-object coupling would be defined as a comfortabnle grip in chich the hand can be easily wrapped around the object (see note 6 below).	For containers of optimal design with no handles or hand-hold cut-outs or for loose parts or irregular objects, a “Fair” hand-to-object coupling is defined as a grip in which the hand can be flexed about 90 degrees (see note 4 below).	Lifting non-rigid bags (i.e., bags that sag in the middle).

Based on the coupling classification and vertical location of the lift, the ***Coupling Multiplier (CM)*** is determined from Table 7.

Tab. 7 Coupling Multiplier

Coupling	**Hand Position at Origin or Destination**	
	< 75 cm	> 75 cm
Good	1,00	1,00
Fair	0,95	1,00
Poor	0,90	0,90

2. 2 Lifting Index (LI)

The LI is a term that provides a relative estimate of the level of physical stress associated with a particular manual lifting task. The estimate of the level of physical stress is defined by the relationship of the weight of the load lifted and the recommended weight limit.

The LI is defined by the following equation:

$$LI = \frac{Load \quad Weight}{Recommended \quad Weight \quad Limit} = \frac{L}{RWL} \tag{9}$$

3. SINGLE TASK – CONTINUE

The task variable data are measured and recorded on the task analysis. The horizontal distance at the origin of the lift is 57 cm and the horizontal distance at the destination of the lift is 57 cm. The height of gear-box one is 80 cm and the height of gear-box two is 100 cm. Since the gear-box is not of optimal design and does not have handles or handhold cutouts, the coupling is defined as "fair" (see Table 6). Asymmetric lifting is involved (i.e., A = 30°). The RWL is computed at both the origin and the destination of the lift.

The multipliers are computed from the lifting equation or determined from the multiplier tables.

This single task lifting analysis consist of the following three steps.

Step 1: Measure and record task variables

<table>
<tr><th colspan="2">Object Weight (kg)</th><th colspan="4">Hand Location (cm)</th><th rowspan="2">Vertical Distance (cm)</th><th colspan="2">Asymetric Angle (degrees)</th><th>Frequency Rate</th><th>Duration</th><th rowspan="2">Object coupling</th></tr>
<tr><th colspan="2"></th><th colspan="2">Origin</th><th colspan="2">Destination</th><th>Origin</th><th>Destination</th><th>lifts/min</th><th>(HRS)</th></tr>
<tr><th>L (AVG)</th><th>L (Max)</th><th>H</th><th>V</th><th>H</th><th>V</th><th>D</th><th>A</th><th>A</th><th>F</th><th></th><th>C</th></tr>
<tr><td>5,8</td><td>5,8</td><td>57</td><td>80</td><td>57</td><td>100</td><td>30</td><td>30</td><td>30</td><td>0,5</td><td>79 sek</td><td>Fair</td></tr>
</table>

Step 2: Determine the multipliers and compute the RWL´s

RWL = LC . HM . VM . DM . AM . FM . CM

Origin

LC = 23 kg
HM = 25/H = 25/57 = 0,44
VM = 1-0,003 |V-75| = 1-0,003 |80-75| = 0,98
DM = 0,82 + (4,5/D) = 0,82 + (4,5/30) = 0,97
AM = 1 – 0,0032 . A = 1 – 0,0032 . 30 = 0,90
FM = 0,97
CM = 0,95

RWL = 23 . 0,44 . 0,98 . 0,97 . 0,90 . 0,97 . 0,95 = 7,97 kg

Destination

LC = 23 kg
HM = 25/H = 25/57 = 0,44
VM = 1-(0,003 |V-75| = 1-0,003 |100-75| = 0,92
DM = 0,82 + (4,5/D) = 0,82 + (4,5/30) = 0,97
AM = 1 – 0,0032 . A = 1 – 0,0032 . 30 = 0,90
FM = 0,97
CM = 0,95

RWL = 23 . 0,44 . 0,92 . 0,97 . 0,90 . 0,97 . 0,95 = 7,48 kg

Step 3: Compute the lifting index

Origin

$$LI = \frac{L}{RWL} = \frac{5,8}{7,97} = 0,72$$

Destination

$$LI = \frac{L}{RWL} = \frac{5,8}{7,48} = 0,77$$

As shown, the RWL for this activity is 7,97 kg. at the origin and 7,48 kg at the destination. The weight to be lifted (5,8 kg) is less than the RWL at the origin (7,97 kg) and at the destination (7,48 kg). The LI is 0,72 at the origin, and the LI is 0,77 at the destination. These values indicate that the lift is not stressful and that some healthy workers would not find this task physically stressful.

Literature

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[3] Chengalurt, S. N. – Rodgers, S. H. – Bernard, T. E.: KODAK'S Ergonomic Design for People at Work. The Eastman Kodak Company, USA, 2004. ISBN 0-471-418663-∃