MIE1411H

Ankh Morpork Postal Service Case Study Report

Group 4:

Katy Tseng: 998530754

Laila Hassanali: 1010727359

Marina Ibrahim: 1008679681

Min Woo Kong: 1008691435

1. Overview of Work Activities & Schedules

The Ankh Morpork Postal Service (AMPS) operates in a dynamic environment where the delivery landscape has evolved significantly over the past decade, with approximately one-third of its deliveries now comprising packages of varying sizes and weights. An ergonomic assessment of small and large package deliveries has been requested by AMPS.

Each mail carrier is assigned a specific geographic area for delivery, utilizing their truck as a base of operations. Shifts are standard day shifts of 8 hours duration (9 am to 5 pm), and deliveries are expected to proceed regardless of weather conditions.

However, AMPS faces challenges, notably an increase in reported acute and chronic musculoskeletal disorders (MSDs), specifically lower back pain and shoulder tendinitis among its workers. Company safety records also show one of the main reasons for short-term and long-term disability claims are slip, trips and falls.

This ergonomics assessment aims to evaluate mail carriers' job tasks at AMPS and identify possible areas of risk.

General Facts:

1. Mail carriers drive trucks within city limits and park the truck in front of a dwelling where a package is to be delivered.
2. Truck maintenance and maintenance records are up to date.
3. Mail carriers are educated on various topics that the company declares necessary and training records are maintained. Training modules can be repeated annually or as necessary.
4. Noise levels within the neighbourhoods never exceed 80dB.
5. Mail carriers work independently.
6. Shifts are 8 hours per day, 5 days per week. One hour per day is dedicated to rearranging packages/mail within the truck.
7. Deliveries are expected regardless of weather. Ankh Morpork's weather mimics Toronto, Ontario.

8. A mail carrier's average weight for male or female are 84.60kg and 66.80 kg respectively [20].
9. The 75th percentile of female and male population is capable of performing the job tasks of a mail carrier in a safe manner.
10. Total number of packages delivered: 200 packages.
    - Approximately 67 packages delivered are large. Large package weights are limited to 30 kg and must not exceed 100cm x 50cm x 50cm.
    - Approximate 133 packages delivered are small. Small packages weigh up to 2kg and are packaged in small boxes or bubble mailers.
11. Mail truck load consists of:
    - Mail trays are containers with dimensions of 100cm x 50cm x 50cm, that hold various small lightweight mail such as bubble mailers, letter and envelope documents and when full it weighs a total of approximately 30.00kg. As the deliveries occur, the weight of the tray decreases to approximately 5.00 kg before the mail carrier rearranges his mail.
    - Packages containing an object or group of objects packed in a box for mailing are of various weights and sizes from 2.00kg up to 30.00kg

2. Identification of Potential Ergonomic Issues

From the overview of AMPS operations for mail carriers, several key areas of concern have been identified. These include repetitive motions, awkward postures, excessive force requirements, and inadequate organization, all of which have the potential to contribute to musculoskeletal disorders (MSDs) and other ergonomic-related concerns. Additionally, the initial overview has highlighted the presence of temperature and vibration risks. The recognition of these potential risks underscores the importance of proactive measures to address ergonomic concerns comprehensively. By identifying and analyzing these ergonomic issues, AMPS can enhance employee health, productivity, and overall workplace satisfaction.

3. Selection & Justification of Key Ergonomic Issues

One prominent concern is the task of lifting and carrying packages from the truck and subsequently to delivery locations. This repetitive lifting and carrying can lead to

musculoskeletal strain and injuries if not executed with proper technique or equipment. The task of reorganizing packages within the truck also presents ergonomic challenges, especially concerning lifting and carrying motions in confined spaces. Assessing the organization of packages and implementing ergonomic solutions can significantly reduce the risk of injuries among employees.

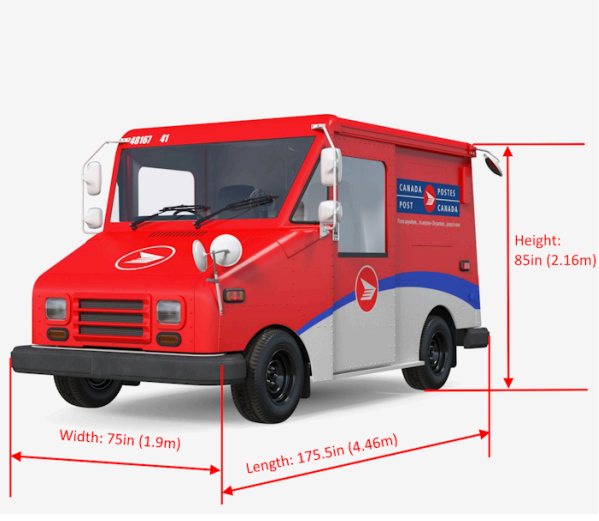
Slips, trips, and falls within a workplace are a prevalent injury concern. A mail carrier's workplace is highly variable due to different property configurations from the street to the entrance. These accidents are common and can occur due to factors like wet or uneven surfaces, cluttered walkways, and poor lighting.

Employees are also exposed to heat or cold stress due to the nature of their work, which can cause discomfort, fatigue, and potential health risks. It is imperative to implement measures to protect employees from temperature-related hazards.

Lastly, prolonged exposure to vehicle vibrations while driving poses a risk of discomfort and health issues.

By analyzing these key ergonomic issues, AMPS can potentially enhance employee safety, reduce the risk of injuries, and promote overall workplace well-being and productivity. Implementation of proactive measures to mitigate these risks ensures a safe working environment for all employees.

4. Analysis of Key Ergonomic Issues



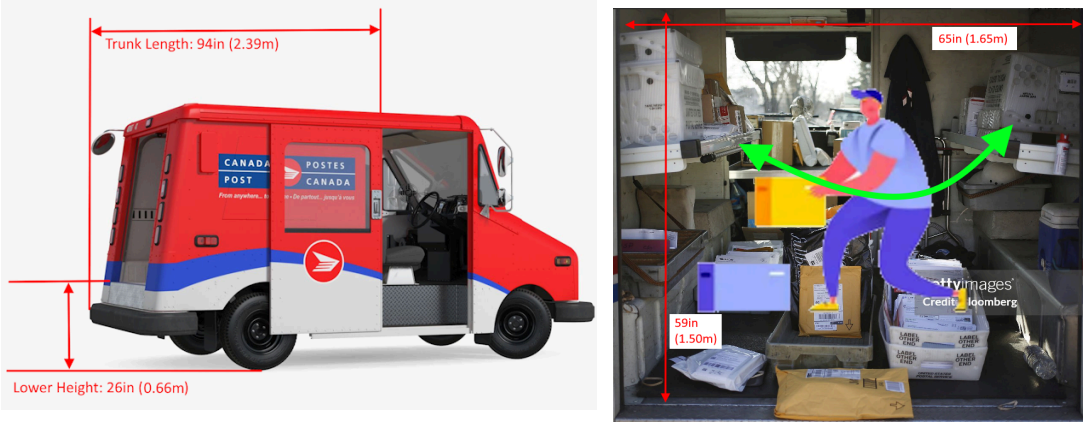


Figure 1 – Canada Post Mail Delivery Truck Dimensions [7,8]

4.1 Reorganizing of the Mail Truck

In this section, we will investigate one of the crucial tasks performed by mail carriers: reorganizing mail trays and packages within the truck to optimize delivery efficiency. Packages are put onto the truck by the mail distribution center before the mail carrier starts their work day. The dimensions of the truck were calculated from Figure 1: 2.39m x 1.65m x 1.50m (L x W x H). Shelves are located at waist height and overhead to place packages and mail trays. Using the National Institute for Occupational Safety & Health (NIOSH) method, we assessed ergonomic risks associated with lifting, lowering, and twisting. The Liberty Mutual method, incorporating data from the 75th percentile of both female and male populations, considers physical capabilities when assessing activities related to lifting and lowering, ensuring adequate consideration of the majority of mail carriers. The UTAH estimation method estimated the force involved in these activities and suggested improvements. Lastly, Rapid Upper Limb Assessment (RULA) scores were calculated to evaluate ergonomic risks of the upper limb associated with repetitive activities related to lifting and lowering.

Lifting, Lowering, and Twisting case inside of truck: **NIOSH method**

Table 1 –NIOSH Equation & Values

Items		**Value - Mail Tray (Metric)**	**Value - Package (Metric)**
Load Constant (LC)		23kg	
Horizontal Multiplier (HM)	25/H	1	
Vertical Multiplier (VM)	1 – (0.003 X |V – 75|)	0.775	
Distance Multiplier (DM)	0.82 + (4.5/D)	0.85	
Frequency Multiplier (FM)	From Table 5	0.88	0.91
Asymmetric Multiplier (AM)	1 – (0.0032A)	0.424	
Coupling Multiplier (CM)	From Table 7	1.00	
Recommended Weight Limit (RWL)	*LC X HM X VM X DM X FM X AM X CM*	5.65kg	5.85kg
Lifting Indicator (LI) for Mail Box	Load Weight (Mail Box) / RWL	0.885 ≤ 1	
Lifting Indicator (LI) for Package	Load Weight (Package) / RWL		5.13 ≥ 1

(Please refer to the Appendix A1 for the calculations.)

Above findings demonstrate that lifting or lowering the mail tray, or twisting the torso while carrying the mail tray is considered safe due to the Lifting Index (LI) being below 1. This indicates that the load weight is below the recommended limit. However, handling packages weighing up to 30 kg poses significant risks to developing MSDs. Therefore, reorganizing the mail trays within a truck is acceptable, while reorganizing the package within a truck is not acceptable.

Lifting and Lowering inside of truck: **Liberty Mutual (LM-MMH) method [6]**

Table 2 – Comparison using LM-MMH (75th Percentile of Population)

Items	**Sex**	**Freq.**	**Max Allowed Lift (kg)/%Capable**	**Max Allowed Lower (kg)/%Capable**	**Safety Concern & Comments**
Mail Tray (5kg)	M	3/min	28.8/99.9	31.0/99.8	Acceptable
	F		12.3/99.5	12.5/98.7	Acceptable
Package (30kg)	M	2/min	31.7/79.8	33.7/83.2	Acceptable
	F		13.0/0.0	13.3/0.5	Not Acceptable

(Please refer to the Appendix A1 for the calculations.)

When considering the gender of employees, the above findings also indicate that the task of repetitive lifting and lowering packages is not acceptable for female employees. This is due to the weight of the load exceeding the maximum weight of safely performing the task.

Lifting and Lowering inside of truck: **Utah Estimation of Back Compressive Force Method**

Job	Analyst
Mail Carrier - Male for Mail Tray (5kg)	
Task	Date
Rearranging in a Canada Post Mail Delivery Truck Trunk	

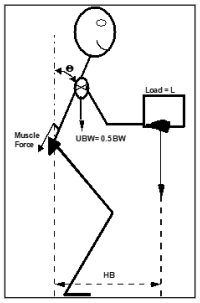
Measure	Symbol	Value
Body Weight [kg] Average body weight for an even gender distribution is 75 kg	BW	84.6 [kg]
Load [kg]	L	5.0 [kg]
Horizontal Distance [m] Hands to lower back {L5 - S1 Joint}	HB	1.00 [m]
Back Posture (Angle from Vertical)	θ	43 [°]
	Sin θ	0.68 [--]

Contributor	Computation	Value [N]
Back Posture A = 29 (BW) sin θ	29 * (85) * (0.68)	1673
Load Moment B = 190 (L*HB)	190 * (5.0) * (1.00)	950
Direct Compression C = 7.5 [(BW)/2 + L]	7.5 * {(85)/2 + (5.0)}	322
Estimated Compressive Force F_c = A + B + C	Comparison Value: 3100 N	2945

Job	Analyst
Mail Carrier - Male for Package (30kg)	
Task	Date
Rearranging in a Canada Post Mail Delivery Truck Trunk	

Measure	Symbol	Value
Body Weight [kg] Average body weight for an even gender distribution is 75 kg	BW	84.6 [kg]
Load [kg]	L	30.0 [kg]
Horizontal Distance [m] Hands to lower back {L5 - S1 Joint}	HB	1.00 [m]
Back Posture (Angle from Vertical)	θ	43 [°]
	Sin θ	0.68 [--]

Contributor	Computation	Value [N]
Back Posture A = 29 (BW) sin θ	29 * (85) * (0.68)	1673
Load Moment B = 190 (L*HB)	190 * (30.0) * (1.00)	5700
Direct Compression C = 7.5 [(BW)/2 + L]	7.5 * {(85)/2 + (30.0)}	347
Estimated Compressive Force F_c = A + B + C	Comparison Value: 3100 N	7720



This method is based on that of Donald S. Bloswick in Bloswick, D. S. and Villnave, T. "Ergonomics (Chap 54)". In Harris, R. E. (ed), Patty's Industrial Hygiene and Toxicology, 5th ed. Vol. 4, New York: John Wiley and Sons, 2000

This workbook was initially developed by Victor Caravello, Lt. Colonel United States Air Force

Job	Analyst
Mail Carrier - Female for Mail Tray (5kg)	
Task	Date
Rearranging in a Canada Post Mail Delivery Truck Trunk	

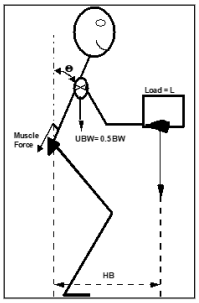
Measure	Symbol	Value
Body Weight [kg] Average body weight for an even gender distribution is 75 kg	BW	66.8 [kg]
Load [kg]	L	5.0 [kg]
Horizontal Distance [m] Hands to lower back {L5 - S1 Joint}	HB	1.00 [m]
Back Posture (Angle from Vertical)	θ	43 [°]
	Sin θ	0.68 [--]

Contributor	Computation	Value [N]
Back Posture A = 29 (BW) sin θ	29 * (67) * (0.68)	1321
Load Moment B = 190 (L*HB)	190 * (5.0) * (1.00)	950
Direct Compression C = 7.5 [(BW)/2 + L]	7.5 * {(67)/2 + (5.0)}	256
Estimated Compressive Force F_c = A + B + C	Comparison Value: 3100 N	2527

Job	Analyst
Mail Carrier - Female for Package (30kg)	
Task	Date
Rearranging in a Canada Post Mail Delivery Truck Trunk	

Measure	Symbol	Value
Body Weight [kg] Average body weight for an even gender distribution is 75 kg	BW	66.8 [kg]
Load [kg]	L	30.0 [kg]
Horizontal Distance [m] Hands to lower back {L5 - S1 Joint}	HB	1.00 [m]
Back Posture (Angle from Vertical)	θ	43 [°]
	Sin θ	0.68 [--]

Contributor	Computation	Value [N]
Back Posture A = 29 (BW) sin θ	29 * (67) * (0.68)	1321
Load Moment B = 190 (L*HB)	190 * (30.0) * (1.00)	5700
Direct Compression C = 7.5 [(BW)/2 + L]	7.5 * {(67)/2 + (30.0)}	281
Estimated Compressive Force F_c = A + B + C	Comparison Value: 3100 N	7302



This method is based on that of Donald S. Bloswick in Bloswick, D. S. and Villnave, T. "Ergonomics (Chap 54)". In Harris, R. E. (ed), Patty's Industrial Hygiene and Toxicology, 5th ed. Vol. 4, New York: John Wiley and Sons, 2000

This workbook was initially developed by Victor Caravello, Lt. Colonel United States Air Force

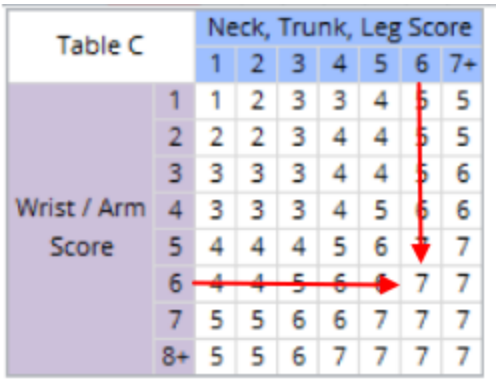
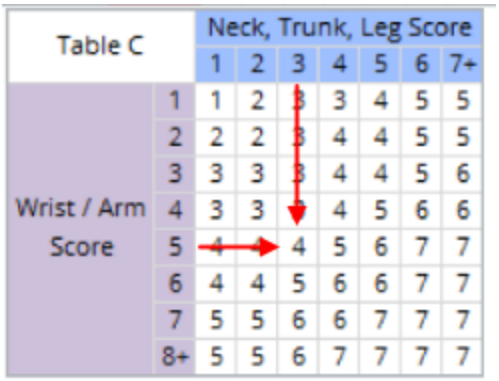
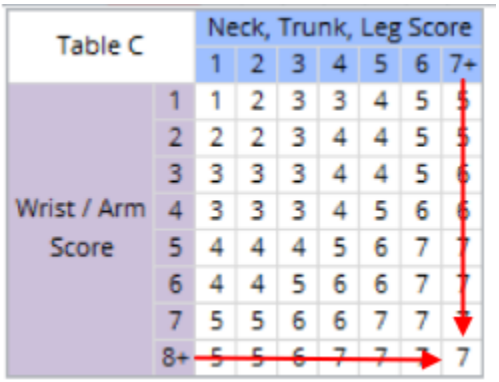
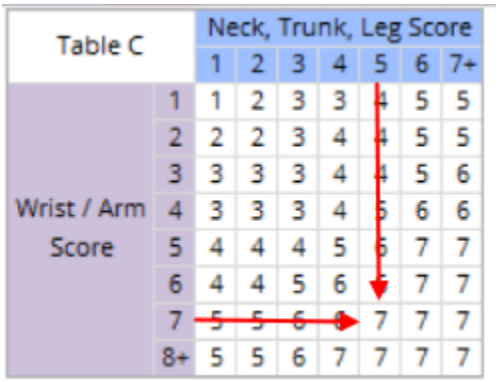
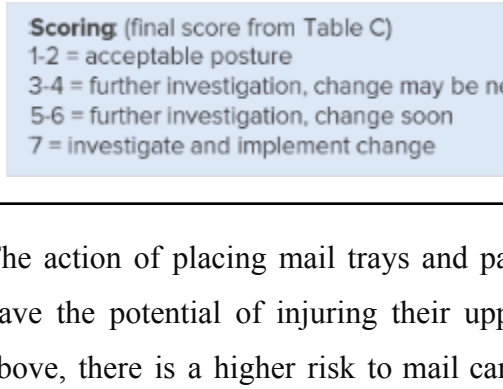
Figure 2 - Utah Estimation of Back Compressive Force

The Utah Estimation of Back Compressive Force suggests that for safe lifting practices, low back compression forces should not exceed 3100N. The forces required to hold the mail tray (Male: 2945N, Female: 2527N) are lower than 3100N, while the force required for handling the 30kg package (Male: 7720N, Female: 7302N) significantly exceeds 3100N. This indicates an increased risk of lower back injury when lifting large packages of 30 kg.

Re-organization inside of truck: **Rapid Upper Limb Assessment (RULA) Score**

Table 3 – Comparison using RULA Score (Please refer to Appendix A1 for full charts)

Placing Mail Tray on Over Head Shelves - RULA Score of 7	Placing Mail Tray on Waist Level or Lower Shelves - RULA Score of 4

<table>
<tr>
<td> 
</td>
<td> 
</td>
</tr>
<tr>
<td>Placing Packages on Overhead Shelves - RULA Score of 7</td>
<td>Placing Packages on Waist Level or Lower Shelves - RULA Score of 7</td>
</tr>
<tr>
<td> 
</td>
<td> 
</td>
</tr>
<tr>
<td> 
</td>
<td>Only RULA scores of 1 or 2 indicate acceptable posture.</td>
</tr>
</table>

The action of placing mail trays and packages on shelves poses a risk to mail carriers as they have the potential of injuring their upper limbs. However, as reflected by the RULA scores above, there is a higher risk to mail carriers if packages are placed overhead compared to mail trays (as reflected in a RULA score of 7 vs. 4, respectively).

4.2 Lifting, Carrying and Lowering of Packages from Truck to Residences

The main purpose of the job of a mail carrier is delivering packages and mail to hundreds of residents per day. Residences can vary from individual homes to multiple unit dwellings. The role of a mail carrier is physically demanding due to the high frequency of lifting, carrying and lowering of packages of various weights and sizes.

This job task has a high risk of MSDs, specifically to the lower back. This section will investigate the risks associated with delivering small and large packages from the truck to residences and will discuss the recommended weights to be lifted, carried, and lowered for the specific distances and frequencies. Using the NIOSH method, we assessed ergonomic risks associated with carrying, lifting, lowering, and twisting. The Liberty Mutual method, incorporates data from the 75th percentile of both female and male populations and takes into consideration physical capabilities when assessing activities related to lifting can carrying, ensuring adequate consideration of the majority of mail carriers.

Figure 3 - Example of maximum size 50x50x100cm package being delivered [21]

The figure below shows the distance the mail carrier walks while carrying a package or other mail from the parked truck to the house. The total walk is approximately 10 meters.

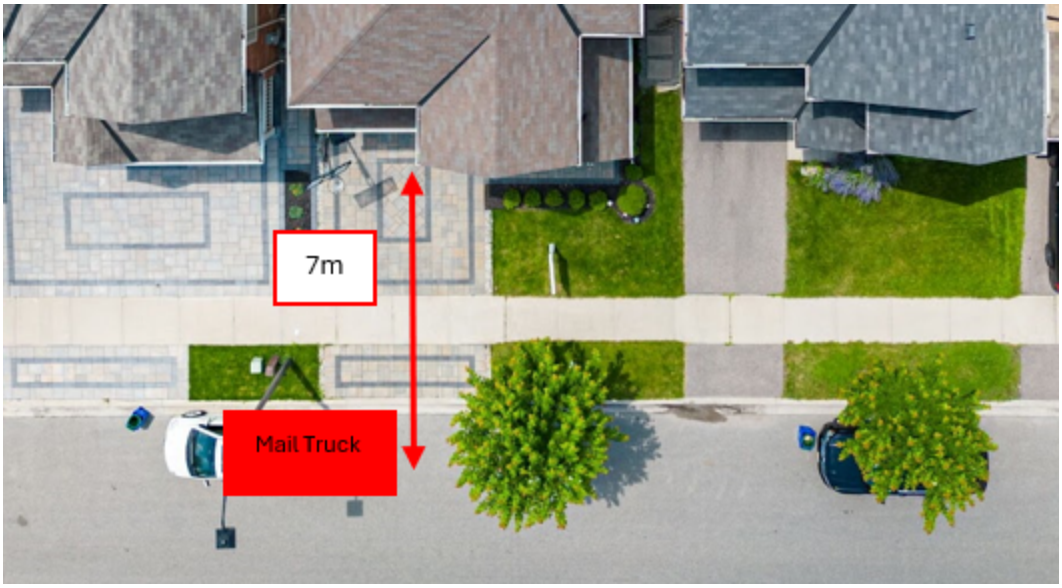


Figure 4 - Carrying dimensions

Inputs for Job Assessment

Table 4 - Inputs

Lifting, Carrying, Lowering Shift	**7 hours**
Lifting Point (Truck Bed)	**66 cm**
Lowering Point (top of 4 steps)	**50 cm**
Walking Distance Carrying Package/mail	**10 m**
Total number of packages delivered [18][20] based on experiences of mail carrier	**200 packages**
⅓ of packages are large size mail	**67 packages**
⅔ of packages are small size mail	**133 packages**
Size of large package	**50cmx50cmx100 cm**
Size of small package	**5cmx5cmx10cm**
Weight of large package	**30 Kg**
Weight of small package	**2 kg**
Elbow length in normal position of 75 percentile males to ground [16]	**111.6 cm**
Elbow length in normal position of 75 percentile females to ground [16]	**103.4cm**
Frequency for large packages 67 lifts/ (7hrs * 60 mins)	**0.16 lifts/min or 1 lift every 6.25 mins**
Frequency for small mail 133 lifts/ (7hrs * 60 mins)	**0.32 lifts/min or 1 lift every 3.13 mins**
Lifting for males: Elbow length 111.6cm - Truck bed 66cm	**45.6cm**
Lifting for females: Elbow length 103.4cm - Truck bed 66cm	**37.4 cm**

Lowering for males: Elbow length 111.6cm - Top of stairs 50cm	**61.6cm**
Lowering for females: Elbow length 103.4cm - Top of stairs 50cm	**53.4cm**

NIOSH method

Table 5 - NIOSH Equation & Values

Items		**Value - Package 30 Kg (Metric)**	**Value - Mail 5 Kg(Metric)**
Load Constant (LC)		**23kg**	
Horizontal Multiplier (HM)	25/H	**0.55**	**1.11**
Vertical Multiplier (VM)	1 – (0.003* |V – 75|)	**M: 0.89, F:0.91**	
Distance Multiplier (DM)	0.82 + (4.5/D)	**1.1**	
Frequency Multiplier (FM)	From NIOSH Table 5	**0.85**	**0.81**
Asymmetric Multiplier (AM)	1 – (0.0032A)	**1**	
Coupling Multiplier (CM)	From NIOSH Table 7	**1**	
Recommended Weight Limit (RWL)	*LC X HM X VM X DM X FM X AM X CM*	**M:10.5 F: 10.7**	**M:20.2 F: 20.7**

Lifting Indicator (LI) for Package	Load Weight (Package) 30 kg / RWL(Av) 10.6	**2.83**	
Lifting Indicator (LI) for Mail	Load Weight (Mail) 2kg/ RWL(Av) 20.45		**0.098**

Above findings demonstrate that lifting, carrying, and lowering small packages (2kg mail) is considered safe due to the Lifting Index (LI) being below 1, indicating a load weight below the recommended limit. However, handling packages weighing up to 30kg poses a possible risk to developing MSDs as the LI is above 1. Therefore, lifting, carrying and lowering small packages is acceptable while large packages are not.

Liberty Mutual Manual (LMM) [6]

Table 6 – Comparison using LM-MMH (75 Percentile)

Lift/ Lower	**Items**	**Sex**	**Freq. times/min**	**Max Allowed Lift (kg)/%Capable**	**Max Allowed Lower (kg)/%Capable**	**Safety Concern & Comments**
	Mail (2kg)	M	0.32	45.5 kg/100%	47.2 kg/99.9%	Acceptable
		F		19.4 kg/100.0%	19.7 kg/99.9%	Acceptable
	Package (30kg)	M	0.16	35.3 kg/86.8%	36.7 kg/87.5%	Acceptable
		F		13.9 kg/0.1%	14.1 kg/1.3%	Not Acceptable
Carry	**Items**	**Sex**	**Freq. times/min**	**Max Allowed Carried (kg)/%Capable**		**Safety Concern & Comments**
	Mail (2kg)	M	0.32	23 kg / 100%		Acceptable
		F		15.0 kg/100%		Acceptable

	Package (30kg)	M	0.16	25.6 kg/56.6%	Not Acceptable
		F		15.9 kg/0.5%	Not Acceptable

(Please refer to the Appendix A2 for the calculations.)

LMM equations conducted show that both males and females are 99.9% capable of lifting, carrying, and lowering small packages (2kg mail) safely with the specified frequency. However, lifting and lowering large packages is deemed unsafe for females and mostly safe for males. Carrying large packages is unsafe for both males and females. This means that performing these tasks with large packages may pose a risk of injury.

4.3 Slips, Trips and Falls

Slips, trips and falls are a common reason for injuries in various occupational settings. Uneven sidewalks/pavement/flooring, wet surfaces, and cluttered pathways are the biggest potential for accidents. Tripping hazards also include cords, rugs, stairs, and steps. Icy conditions are more dangerous as 70% of all falls are due to icy, wet, or snowy surfaces. In Ontario, about 20,000 emergency department visits and 2,000 hospitalizations are due to falls on ice [14].

Figure 5 - Delivery man slipping and falling on a slippery porch [10].

4.4 Heat and Cold Stress

Heat and cold stress are environmental hazards with a potential to cause physical and cognitive distress. AMPS workers are subject to the outdoor environment in order to deliver packages, as such it is appropriate to assess workers' risk of heat and cold stress. This assessment will focus on an average female and male worker in generally good health. It is assumed that mail and packages are delivered regardless of weather conditions. An analysis of heat and cold stress is performed on extreme weather condition days and is used as a benchmark for plausible temperature conditions a worker can be exposed to.

4.4a Heat Stress

Risk of heat exposure is determined by considering factors such as the environment (humidity, wind, temperature, and radiant heat), clothing, and workload (metabolic rate) [12]. Heat exposure can cause increased irritability, loss of concentration, and loss of the ability to do heavy tasks [12]. Heat related illnesses include heat cramps, heat exhaustion, and heat stroke. Individual worker characteristics may increase the risk of heat stress and additional monitoring will be required for these individuals. An employer and/or supervisor should take note of the employees who are overweight; over 45 years of age; have medication conditions such as heart disease, high blood pressure, respiratory disease, and uncontrolled diabetes; and female workers as these workers have an increased risk of heat stress [12].

The hottest day in Ankh Morpork recorded in 2023 was September 4th with a temperature of 32.9 °C [23].

Table 7 - Working Environment Conditions on Hottest Day in Ankh Morpork [11]

	September 4th, 2023
Air Temperature	91°F/32.9 °C
Cloud Cover	Clear (solar irradiance of 990 W/m^2)
Wind Speed	16 mph

Relative Humidity	46%
Barometric Pressure	29.26 inHg
Clothing Adjustment Factor	0 (Work clothes)

A Wet Bulb Globe Temperature (WBGT) meter can measure humidity, air movement, radiant heat, and temperature [12]. WBGT is a combination of three measurements: air temperature, natural wet bulb temperature, and black globe temperature [11]. Air temperature is the equivalent of a typical outdoor thermometer. Natural wet bulb temperature is measured by a thermometer wrapped in a wet cloth. The wet cloth simulates the cooling effect of sweat, which is influenced by wind and humidity. It also considers the effects of sunlight. Black globe temperature is measured with a thermometer inside a black globe, which mimics how hot it feels in direct sunlight. For an outdoor environment with direct sun exposure, the following formula is used to determine WBGT temperature:

$$WBGT = 0.7 \times Temp_{wet\ bulb} + 0.2 \times Temp_{globe} + 0.1 \times Temp_{air}$$

Without a WBGT meter, WBGT can be estimated using the Occupational Safety and Health Administration (OSHA) Outdoor WBGT Calculator [13]. The WBGT is 29°C, when assuming solar irradiance of 990 W/m^2 for a sunny day (see appendix *table A3: Solar Irradiance based on Reported Cloud Cover*).

Clothing contributes to temperature, therefore a clothing adjustment factor (CAF) is added to the WBGT (see appendix *table A4: Clothing Adjustment Factor*) [12]. A mail carrier would typically wear work clothes consisting of a t-shirt/long sleeve shirt and pants which is a CAF of 0.

$$\text{WBGT Effective} = \text{WBGT Outside} + \text{CAF (Celsius)}$$

$$WBGT_{eff} = 29°C + 0$$

$$WBGT_{eff} = 29°C$$

Metabolic rates represent internal body heat produced as exertion increases. From Compendium of Physical Activities, it can be assumed the metabolic equivalent of task (MET) for a mail carrier who is walking to deliver mail is 2.3 [15]. The MET is a ratio of physical activity energy

cost in mL/kg relative to standardized resting metabolic rate of 3.5 mL/kg/min. This value can be converted to watts to categorize the worker into the American Conference of Governmental Industrial Hygienists (ACGIH) workloads [1]. The weight of an average female is 66.80 kg and average male is 84.60kg [20].

METS to Watts = METS x body weight in kg x 1.22

Female Metabolic Rate (Watts) = 2.3 x 66.80kg x 1.22

Female Metabolic Rate (Watts) = 187.44 Watts

Male Metabolic Rate (Watts) = 2.3 x 84.60kg x 1.22

Male Metabolic Rate (Watts) = 237.39 Watts

Based on metabolic work rate, a female or male work category is light (180-300 Watts) (*see appendix table A2 - Work Category based on Metabolic Rate in Watts*).

Table 8 - ACGIH Screening Criteria for Heat Stress Exposure (WBGT values in °C) for 8 hour work day five days per week with conventional breaks

Allocation of Work in a Work/Rest Cycle	Acclimatized				Action Limit (Unacclimatized)			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75-100%	31.0	28.0	--	--	28.0	25.0	--	--
50-75%	31.0	29.0	27.5	--	28.5	26.0	24.0	--
25-50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
0-25%	32.5	31.5	30.5	30.0	30.0	29.0	28.0	27.0
Notes: Assumes 8-hour workdays in a 5-day work week with conventional breaks. Threshold Limit Values (TLV) assume that workers exposed to these conditions are								

adequately hydrated, are not taking medication, are wearing lightweight clothing (long-sleeve shirts and pants), and are in generally good health.

After the WBGT is measured, a clothing adjustment factor is added, and the workload is translated into metabolic rate, these values can be compared to the ACGIH TLV & Action Limit table to determine the risk for exposure to heat stress for unacclimatized workers and for acclimatized workers [1]. For an acclimatized worker (worked for a minimum of 10-14 days in the job), no restriction to the work/rest cycle is required, however for an unacclimatized worker a work/rest cycle of 50%-75% is required to mitigate the risk of heat stress [12].

4.4 b Cold Stress

Cold poses the risk of hypothermia, frostbite, chilblains, and trench foot to cold weather workers. Cold impacts a workers' performance with decreased work efficiency; higher accident rates; decreased sensitivity in fingers; decreased alertness and cognitive abilities; and lower strength and stiff joints. Wind can increase heat loss from a worker. The term "wind chill" is used to describe heat loss from the combination of wind and air temperature therefore it is expressed in temperature-like units for easy comprehension [5]. It can be used as a guideline for appropriate clothing and the possible health effects of the cold.

The ACGIH created recommendations to protect workers from adverse health effects from cold stress (hypothermia and frostbite), with consideration of repeated exposure when working in cold conditions [1]. The coldest day in Ankh Morpork in 2023 was February 3rd with a temperature of approximately -20 °C.

Table 9 - Working Environment Conditions on Coldest Day in Ankh Morpork [23]

	February 3rd 2023
Air Temperature	-2°F/-18.9 °C
Wind Speed	41 mph/65 km/h

WIND CHILL TEMPERATURE INDEX
Frostbite Times are for Exposed Facial Skin

Air Temperature (°C)

Wind Speed (km/h)	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
20	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
25	1	-6	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70
30	0	-6	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
35	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
40	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
45	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
50	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
55	-2	-8	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
60	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
65	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
70	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
75	-3	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
80	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

FROSTBITE GUIDE

Increasing risk of frostbite for most people in 10 to 30 minutes of exposure
High risk for most people in 5 to 10 minutes of exposure
High risk for most people in 2 to 5 minutes of exposure
High risk for most people in 2 minutes of exposure or less

Figure 6 - Wind Chill Temperature Index (ACGIH) [1]

The wind chill on the coldest day in Ankh Morpork in 2023 was -34°C. From the ACGIH frostbite guide, the worker is at high risk for frostbite if skin exposure is greater than 5 to 10 minutes [1]. Environment Canada also suggests a severe risk of hypothermia at this windchill if outside for periods longer than 2 to 5 minutes or faster with this high wind speed.[5].

Analysis Ankh Morpork's hottest and coldest day of 2023 demonstrates an exposure risk for workers to heat and cold stressors. Controls to minimize risk are recommended.

4.5 Vibration

The Ankh Morpork Postal Service delivers their letters and packages by transporting via mail truck. This makes mail carriers' subject to whole-body vibration (WBV) as they spend several

hours of their workday driving. Vibration can enter the body wherever there is contact with vibrating surfaces, such as the seat, steering wheel, and floor pedals [13].

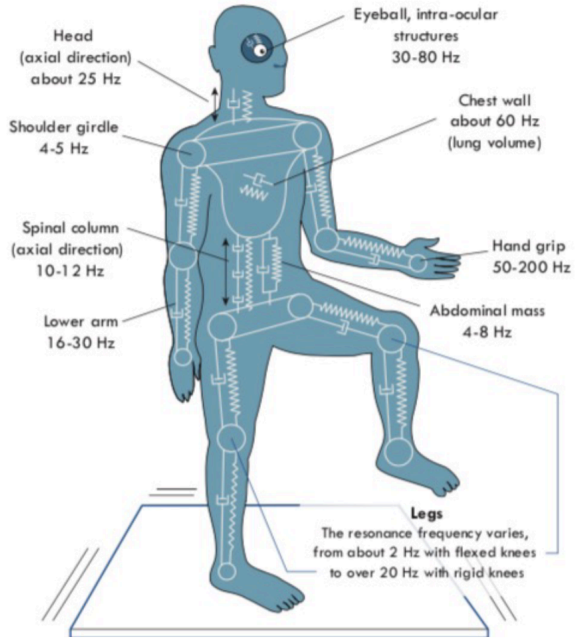


Figure 7 - Image: person on vibrating platform

Each part of the body, as shown in the above diagram, has different resonant frequencies where levels of strain and tissue damage are the highest. The mail carrier is also subject to many other physical health concerns due to WBV such as spinal disorders, MSDs (including discomfort in the back, hands, feet, neck and shoulder), gastrointestinal problems, and reproductive effects. Exposure to these vibrations for prolonged periods of time can result in fatigue and numbness. WBV associated with driving also increases cognitive and physical stress, leading to more driving errors and potentially more car accidents [13].

Notes:

1. The TLV curve coincides with the upper boundary of the Health Guidance Caution Zones defined in ISO 2631-1.[1,2] The TLVs refer to the maximum vector sum of the overall weighted RMS accelerations for a given expected daily exposure duration to which it is believed a majority of operators and occupants of land, air, and water vehicles may be exposed within a 24-hour period with a low probability of health risks. Exposures falling above the TLV or upper ISO boundary are associated with likely health

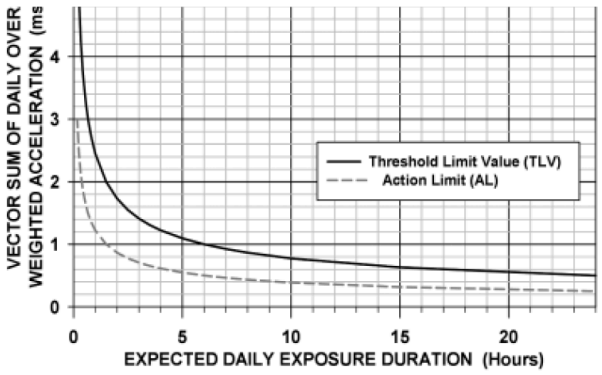


FIGURE 1. Threshold Limit Values (TLVs) and Action Limits (ALs) associated with the upper boundary and lower boundary of the ISO 2631-1 Health Guidance Caution Zones, respectively.[1,2] ***Note:*** Values are constant for exposures at and below 10 minutes (0.17 h).

Figure 8 - The American Conference of Governmental Industrial Hygienists Threshold Limit Values for a 24-hour time period [1]

To ensure the postal truck is producing safe resonant frequencies for the AMPS drivers, vibration analysis was performed. A tool such as the triaxial accelerometer is used to detect vibrations and analyze vibration exposure. They are typically used to measure WBV exposure experienced by people in a seated position, such as the mail carrier when driving. Triaxial accelerometers are the ACGIH measurement tool for analyzing WBV. Ankh Morpork's mail truck is deemed to produce safe resonant frequencies upon vibration analysis, as outlined in a report by the industrial hygienist. They concluded that the vibration frequencies analyzed from the truck were within the threshold limit value (TLV) for an 8-hour shift according to The American Conference of Governmental Industrial Hygienists (chart shown above) [1].

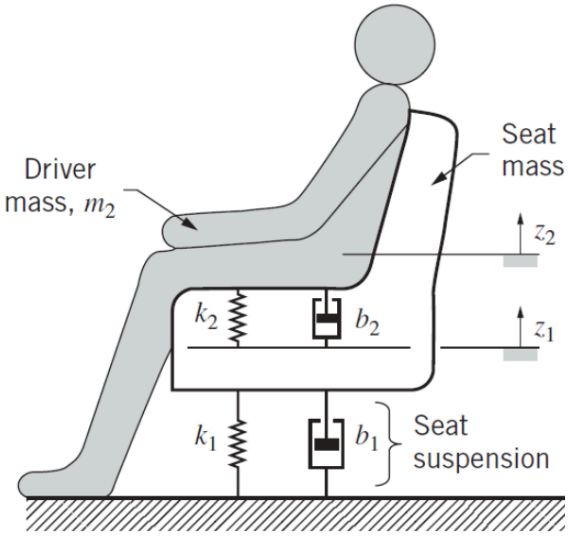


Figure 9- Driver Seat with Seat Suspension [24]

On further analysis, AMPS mail carriers drive mostly on city roads. Minimal excess vibration is experienced with well maintained city roads. In addition, AMPS prioritizes truck maintenance once every 6 months, or earlier if the truck experiences issues. Maintenance includes inspection of suspension and repair and/or replacement as necessary. A well-maintained suspension is a priority at AMPS to ensure that vibration due to roads is further reduced. Quality of suspension is a factor of many when AMPS considers the decommission or purchase of trucks. No mail carriers have reported any injuries or requested modification associated with driving the truck. Each truck seat has an adjustable seat that possesses lumbar support to minimize lower back pain. Mail carriers are trained in seat adjustments and training records are maintained. As such, no further modification to the truck is required to decrease vibration effects on mail carriers at this time.

5. Recommendations

Substituting mail carriers for self guided delivery robots is our ideal solution to the issues addressed above. This would eliminate the need for mail carriers to deliver packages and mail, therefore eliminating musculoskeletal strain and injury that is associated with the job. It would also eliminate the risk of slips and falls, temperature-related stress, and vibration on the driver. Although removing the worker entirely from the scenario and replacing them with a robot is our ideal solution, it is our most expensive upfront solution. Creating a delivery hub where customers

can pick up their packages is also an option that eliminates some of the hazards associated with mail carriers driving to residences. Additional advanced cost analysis and operational feasibility is recommended.

Figure 10 - Autonomous Delivery Robot - $7,138.47 [28]

5.1 Reorganization of Packages in the Truck and Lifting, Carrying and Lowering of Packages from Truck to Residences

The analysis above demonstrated that a reduction of package weight could significantly decrease mail carrier injuries. Package redesign such as adding handles to large packages or reconsidering box dimensions is strongly advised. In terms of package organization, heavier packages can be placed on the floor or on a surface at waist height. Mail trays can be placed on overhead shelves if necessary. Reorganizing packages to be near the truck door when parked will allow for the mail carrier to have easier access and to have better posture while lifting the packages out of the truck. In addition, advising that mail carriers incorporate regular stretching breaks and exercises at an administrative level to help in alleviating strain and maintaining flexibility is recommended. Increasing the number of mail carriers per geographical area will divide physical demand amongst employees. The use of assistive devices to deliver to dwellings, such as carts and dollies, will minimize the physical burden on the body. Purchasing a dolly, as shown below, would minimize the lifting required by workers and therefore would decrease their injury risk at a cheaper cost than a robot or an additional employee.

Figure 11 - Dolly $140 [25]

5.2 Slips, Trips and Falls

Mail carriers work in two environments, where the truck is a constant environment but the delivery route is dynamic. Mail carriers need to maintain a clean and organized truck to prevent slips, trips, and falls accidents. When mail carriers exit the truck to deliver a package, they should scan their surroundings for hazards such as spilled liquids, loose cables, or debris. They should wear appropriate footwear with slip-resistant soles and high Maximum Achievable Angle (MAA) footwear that can provide traction and prevent slips and falls, minimizing the likelihood of slips on slick surfaces. Websites such as “Rate my Treads” [22] can be provided to employees and administration to help choose the most appropriate shoes needed for the job and weather conditions. Purchasing slip resistant boots such as the ones shown below are an example of a cost effective solution.

Figure 12 - WindRiver Men's Back Forty ICEFX Boots - Dark Brown (MMA rating 12 [9]) - $159.99 [26]

5.3 Heat and Cold Stress

AMPS operational goal to deliver packages during weekdays presents a dynamic risk to heat or cold temperatures due to varying daily weather. Analysis of the hottest and coldest day of 2023

demonstrates potential exposure risk for workers. Implementing various controls will mitigate the risk of exposure. As weather changes throughout the day, a thermometer to monitor outdoor temperature including wind speed can be added to any truck. Many administrative controls are also available. Workers and supervisors should be educated about the adverse health effects of cold and heat exposure (including recognition of cold stress/frostbite, hypothermia, heat stress, and hyperthermia); appropriate clothing habits; safe work paces; cooling/rewarming procedures; and emergency procedures in case of heat or cold injury. In cases of an emergency, staff should be trained in first aid or know how to seek medical care when necessary. AMPS should supply appropriate uniforms and schedule more breaks during extreme weather conditions. Scheduling two workers per truck during extreme weather conditions will help each other identify heat/cold stress symptoms if they occur on route. This will help to prevent temperature-related injuries in their early stages. Workers should be given an "adjustment period", where they are able to have a lighter than expected workload and acclimatize to weather if required. Modifying scheduling during these times is recommended. These procedural controls can be integrated into the operational policies of AMPS.

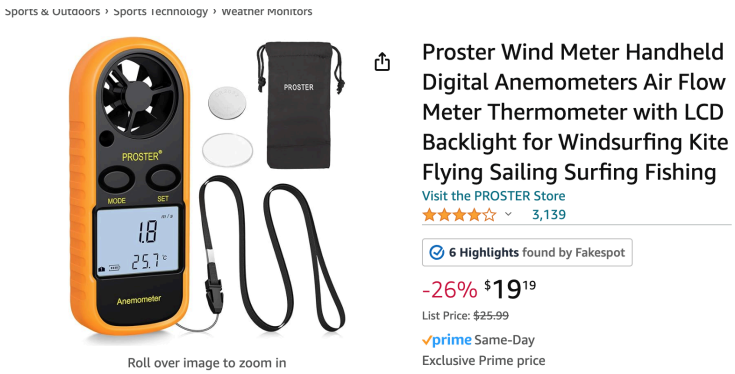


Figure 13 - Handheld Wind Meter and Thermometer - $19.99 [27]

5.4 Vibration

Evaluation of vibration should be ongoing to address any mail carriers' concerns regarding vibration-related musculoskeletal pain. It is advised that AMPS offers annual or as-requested retraining on seat adjustments, in addition to their onboarding training, to ensure that drivers are reminded how to adjust their seat to suit their body dimensions and weight. AMPS should continue to prioritize driver seat selection to decrease the amplification of vibration when

purchasing new trucks. Scheduling breaks and shorter shift times will decrease overall exposure to vibration on a single shift [3].

Estimated benefits for solution options

Option 1 Delivery Robot		
Reduction in claims:		70%
Reduction in workers' comp costs:	$	186,671
Reduction in indirect costs:	$	205,338
Increase in productivity:		10.0%
Productivity value:	$	34,000
Other estimated savings:		
Total estimated annual savings:	$	426,009
Total estimated savings over 3 years:	$	1,278,028
Total estimated savings over 5 years:	$	2,130,046

Option 2 Dolly		
Reduction in claims:		15%
Reduction in workers' comp costs:	$	53,335
Reduction in indirect costs:	$	58,668
Increase in productivity:		5.0%
Productivity value:	$	17,000
Other estimated savings:		
Total estimated annual savings:	$	129,003
Total estimated savings over 3 years:	$	387,008
Total estimated savings over 5 years:	$	645,013

Option 3 Slip Resistant Boots		
Reduction in claims:		10%
Reduction in workers' comp costs:	$	26,667
Reduction in indirect costs:	$	29,334
Increase in productivity:		0.0%
Productivity value:	$	-
Other estimated savings:		
Total estimated annual savings:	$	56,001
Total estimated savings over 3 years:	$	168,004
Total estimated savings over 5 years:	$	280,006

Option 1 Thermometer		
Reduction in claims:		10%
Reduction in workers' comp costs:	$	26,667
Reduction in indirect costs:	$	29,334
Increase in productivity:		0.0%
Productivity value:	$	-
Other estimated savings:		
Total estimated annual savings:	$	56,001
Total estimated savings over 3 years:	$	168,004
Total estimated savings over 5 years:	$	280,006

Figure 14 - Cost Analysis of Control Options [29]

The cost analysis above shows that the delivery robot will provide the greatest savings and largest reduction in workers' compensation costs, with the highest upfront cost. The other options included a dolly and slip resistant boots which will be cheaper upfront with less annual savings, however a smaller reduction in injury claims will still be seen.

Redundancy in controls improves the effectiveness of the controls and decreases the chance of failures in the system, therefore minimizing risk exposure. Implementing the measures above, along with regular monitoring systems, will not only improve ergonomic practices but also prioritize the well-being of AMPS personnel amidst evolving operational demands.

6. References

1. ACGIH. (2023). Policy statement on the uses of TLVs® and BEIs®. In Threshold Limit Values for Chemical Substances and Physical Agents: Biological Exposure Indices TLVs® and BEIs® Based on the Documentation of the (2023 ed.). ACGIH.

2. Bloomberg / Contributeur. (2016, December 22). Mail is seen in the rear of a United States Postal Service [Photograph]. Bloomberg. Editorial no. 630430188. Collection: Bloomberg. https://www.gettyimages.ca/detail/news-photo/mail-is-seen-in-the-rear-of-a-united-states-postal-service-news-photo/630430188?adppopup=true

3. Burdorf, A., & Jansen, J. P. (2006). Predicting the long term course of low back pain and its consequences for sickness absence and associated work disability. Acta Orthopaedica Scandinavica, 77(1), 54-60. https://doi.org/10.1080/17453670610045675

4. Byways.org. (n.d.). Tire Size: 195/75R14. Retrieved from https://www.byways.org/tire/195-75r14/

5. Canadian Centre for Occupational Health and Safety. (n.d.). Cold - Working in cold weather. Retrieved from https://www.ccohs.ca/oshanswers/phys_agents/cold/cold_working.html

6. Daily Mail. (n.d.). Foul-mouthed Amazon deliveryman hits ground THREE TIMES on slippery porch. Retrieved from https://www.dailymail.co.uk/news/article-8880681/Foul-mouthed-Amazon-deliveryman-hits-ground-THREE-TIMES-slippery-porch.html

7. Free3D.com. (n.d.). Canada Grumman LLV Post Car. Retrieved from https://free3d.com/3d-model/canada-grumman-llv-post-car-3862.html

8. Free3D.com. (n.d.). Grumman Canada LLV Post Car Rigged for Maya. Retrieved from https://free3d.com/3d-model/grumman-canada-llv-post-car-rigged-for-maya-4852.html

9. Kite-UHN. (n.d.). Rate my Treads. Retrieved from https://kite-uhn.com/rmt/en

10. National Institute for Occupational Safety and Health. (n.d.). NIOSH Lifting Equation.

11. Nicholas Institute at Duke University. (n.d.). What is Wet Bulb Globe Temperature (WBGT)? Retrieved from https://nicholasinstitute.duke.edu/project/heat-policy-innovation-hub/what-is-wet-bulb-globe-temperature-wbgt

12. Occupational Safety and Health Administration. (n.d.). Section 3: Health hazards - Chapter 4. Retrieved from https://www.osha.gov/otm/section-3-health-hazards/chapter-4

13. Occupational Safety and Health Administration. (n.d.). WBGT calculator. Retrieved from https://www.osha.gov/heat-exposure/wbgt-calculator

14. Ontario Injury Prevention Resource. (2009). Falls on same level involving ice and snow.

15. Pacompendium. (n.d.). Retrieved from https://pacompendium.com/

16. Potvin, J. R., Ciriello, V. M., Snook, S. H., Maynard, W. S., & Brogmus, G. E. (2021). The Liberty Mutual manual materials handling (LM-MMH) equations. Ergonomics, 64(8), 955-970. https://doi.org/10.1080/00140139.2021.1888463

17. Quora. (n.d.). How many houses does the average postman deliver to in a day? [Web page]. Quora. https://www.quora.com/How-many-houses-does-the-average-postman-deliver-to-in-a-day

18. Reddit. (n.d.). 300 Packages per Day. Reddit. https://www.reddit.com/r/AmazonDSPDrivers/comments/v224kd/300_packages_per_day/

19. Save the Post Office. (2016, January 10). Trucks on fire: USPS Long Life Vehicles outlive their lifespan. Retrieved from https://www.savethepostoffice.com/trucks-fire-usps-long-life-vehicles-outlive-their-lifespan/

20. U.S. Army Natick Soldier Research, Development and Engineering Center. (2012). 2012 Anthropometric Survey Of U.S. Army Personnel: Methods And Summary Statistics [Report]. Natick, Massachusetts.

21. ULine, Tall boxes Retrieved from https://www.uline.ca/BL_410/Tall-Boxes

22. University of Waterloo. Centre of Research Expertise for the Prevention of Musculoskeletal Disorders. (n.d.). Factors affecting operator exposure to whole-body vibration. Retrieved from https://uwaterloo.ca/centre-of-research-expertise-for-the-prevention-of-musculoskeletal-disorders/resources/position-papers/factors-affecting-operator-exposure-whole-body-vibration

23. Weather Underground. (n.d.). Weather forecasts, maps, news & alerts. Retrieved from https://www.wunderground.com/

24. Chegg. (n.d.). Case study on dynamic systems modeling, simulation, and control (Lecture on vibration isolation system). Retrieved from

https://www.chegg.com/homework-help/questions-and-answers/case-study-dynamic-systems-modeling-simulation-control-lecture-vibration-isolation-system--q51275217

25. . Uline. (n.d.). Handi-Mover 19" x 29". Retrieved from https://www.uline.ca/Product/Detail/H-115/Platform-Trucks/Handi-Mover-19-x-29?pricode=YE855&gadtype=pla&id=H-115&gad_source=1&gclid=CjwKCAjwnv-vBhBdEiwABCYQA8OxEzZLoLqKe_eBfF14-_WVP5olu7-SGIt9alGY7ZNL6T4gfCc1GBoCYG4QAvD_BwE

26. L'Équipeur. (n.d.). WindRiver Men's Back Forty IceFX Boots - Dark Brown. L'Équipeur. Retrieved from https://www.lequipeur.com/en/pdp/windriver-men-s-back-forty-icefx-boots-dark-brown-78432604f.html

27. Amazon. (n.d.). Proster Anemometers Digital LCD Wind Speed Meter Gauge Air Flow Velocity Measurement Thermometer with Backlight for Windsurfing Kite Flying Sailing Surfing Fishing [Digital]. Amazon. Retrieved from https://www.amazon.ca/Proster-Anemometers-Thermometer-Backlight-Windsurfing/dp/B00KYL3VNS?th=1

28. Marvelmind Autonomous Delivery Robot v100. (n.d.). RobotShop. https://ca.robotshop.com/products/marvelmind-autonomous-delivery-robot-v100

29. MSD Prevention. (2022). Ontario Ergonomics Intervention Cost-Benefit Calculator. MSD Prevention. Retrieved from https://www.msdprevention.com/resource-library/view/ontario-ergonomics-intervention-cost-benefit-calculator.htm

Appendix

A1. Reorganizing

NIOSH method

Calculations:

LC = 23kg (∵ the max recommended load)

HM = 25/H

= 25/25

= 1.0

H = 20 + W/2 for V ≥ 25cm (W is the distance from the mid-point of the line joining the inner ankle bones to a point projected on the floor directly below the load centre. The value of H that can be used is 25cm, assuming the mail trays/packages will be lifted/lowered as close to the body as possible.)

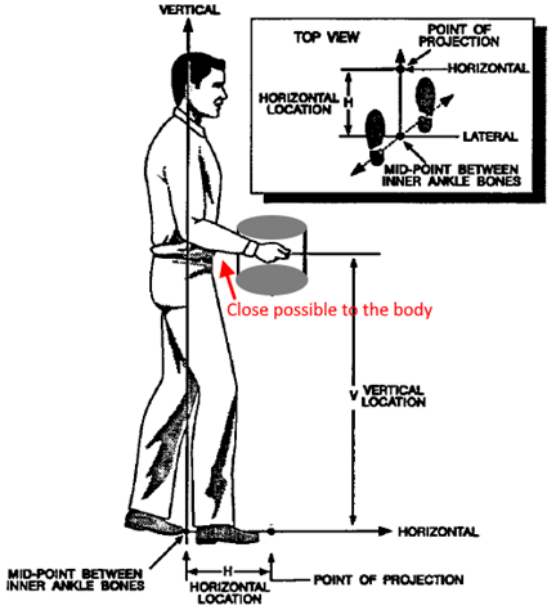


Figure A1 – Horizontal Multiplier value logic

VM = 1 – (0.003 X |V – 75|)

= 1 – (0.003 X |150 – 75|)

= 0.775

DM = 0.82 + (4.5/D)

= 0.82 + (4.5/150)

= 0.85

D = vertical displacement of load (cm), same as V: 150cm

FM = 0.88 (from Table 5)

Mail Tray: Assuming 1 hour / 8 hours (Total working hour) needs to be spent for reorganizing. Lifting and Lowering have to be done after checking the recipient's name and address. => 3 lifts/min can be considered.

FM = 0.91 (from Table 5)

Package: Assuming 1 hour / 8 hours (Total working hour) needs to be spent for reorganizing. Lifting and Lowering have to be done after checking the recipient's name and address. => 2 lifts/min can be considered.

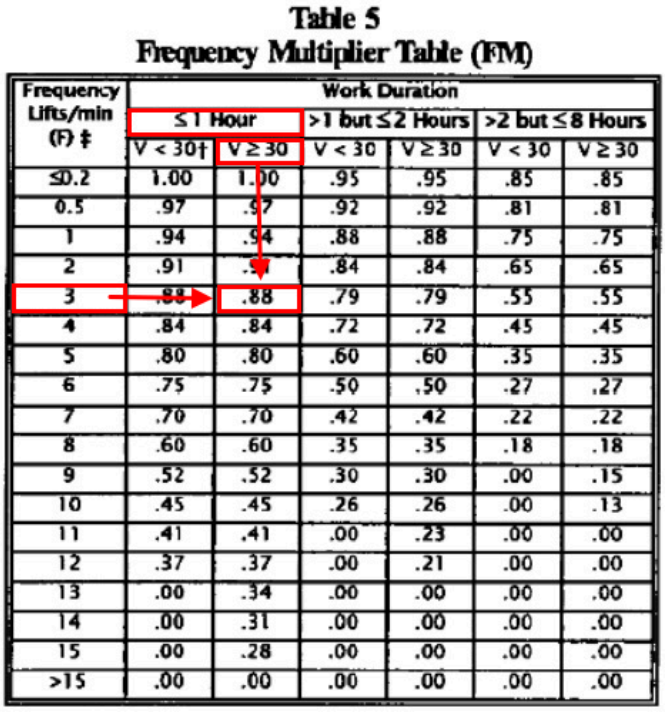


Table 5
Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Figure A2 - FM value logic (Mail Tray)

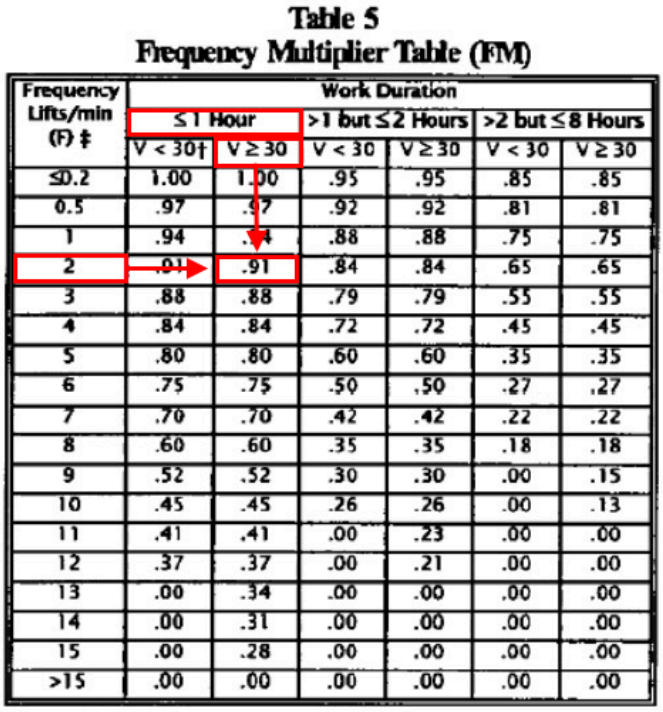


Table 5
Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Figure A3 - FM value logic (Package)

AM = 1 – (0.0032A)

= 0.424

A is 180 degrees since there is a potential to turn around while lifting.

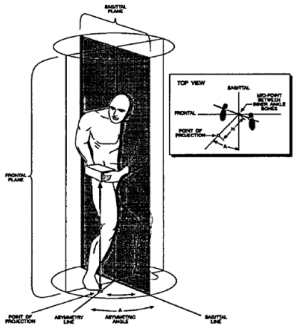


Figure A4 – Asymmetric Multiplier value logic

CM = 1.00

Table 7
Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Table 6
Hand-to-Container Coupling Classification

GOOD	FAIR	POOR
1. 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].	1. 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].	1. Containers of less than optimal design or loose parts or irregular objects that are bulky, hard to handle, or have sharp edges [see note 5 below].
2. For loose parts or irregular objects, which are not usually containerized, such as castings, stock, and supply materials, a "Good" hand-to-object coupling would be defined as a comfortable grip in which the hand can be easily wrapped around the object [see note 6 below].	2. 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].	2. Lifting non-rigid bags (i.e., bags that sag in the middle).

Figure A5 – Coupling Multiplier value logic

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

= 23kg X 1 X 0.775 X 0.85 X 0.88 X 0.424 X 1.00

= 5.65kg (Mail Tray)

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

= 23kg X 1 X 0.775 X 0.85 X 0.91 X 0.424 X 1.00

= 5.85kg (Package)

LI = Load Weight (Mail Tray) / RWL

= 5.00kg/5.65kg

= 0.885 ≤ 1

LI = Load Weight (Package) / RWL

= 30kg/5.85kg

= 5.13 ≥ 1

Liberty Mutual (LM-MMH) method

Male Lift & Lower Case for normal mail tray:

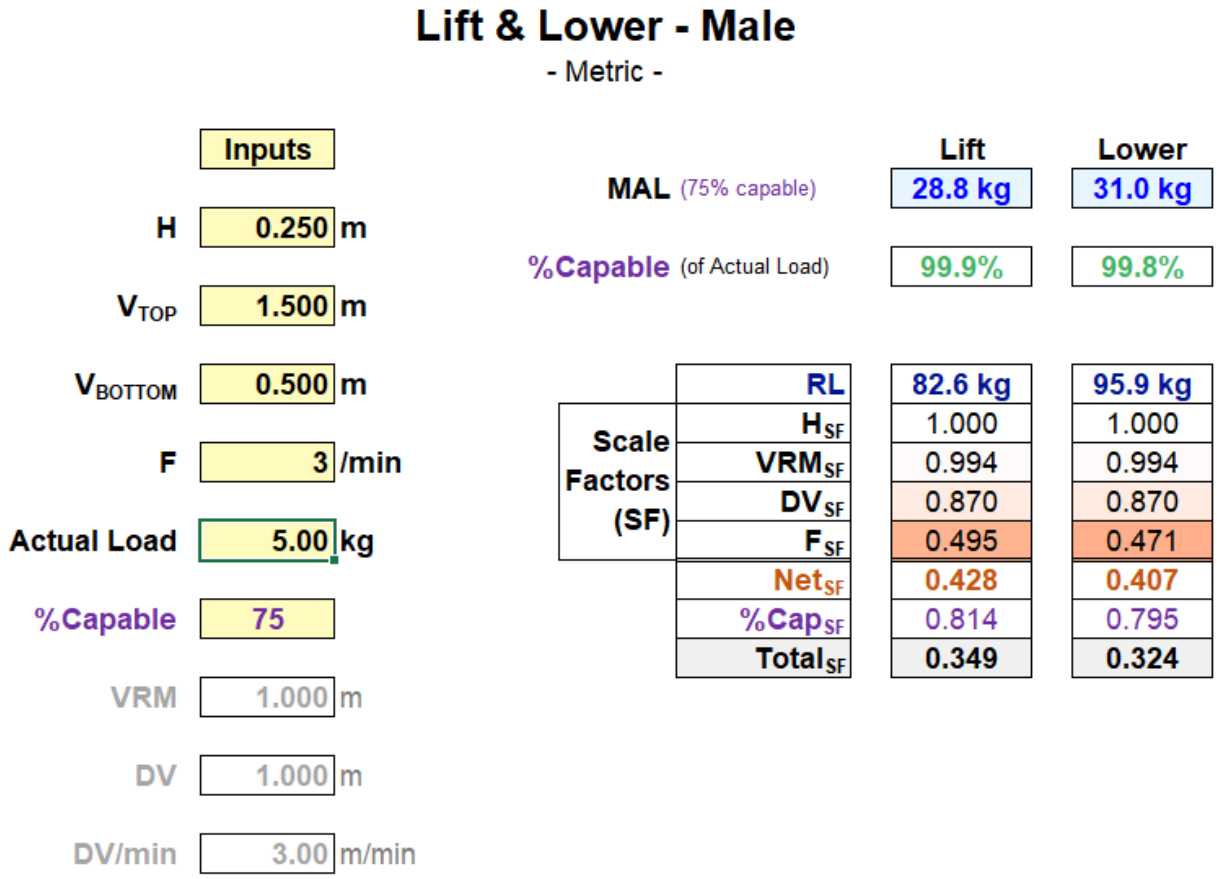


Figure A6 – Normal Mail Tray, LM-MMH Lift & Lower chart for male

For the mail tray having a mass of 5.00kg, a given truck (V TOP), and a width (W) of 0.25m, along with assumptions of a male lifter, and a lift frequency of 3 lifts per 1 minute with 75% of the population, maximum acceptable weight of lift and maximum acceptable weight of lower are calculated as 28.8kg and 31.0kg respectively. The actual load weight (5.00kg) is lower than those values (28.8kg and 31.0kg). Therefore, the lifting/lowering mail box task in a truck is considered safe.

Male Lift & Lower Case for maximum package (30kg):

Lift & Lower - Male

- Metric -

Inputs		
H	0.250	m
V_{TOP}	1.500	m
V_{BOTTOM}	0.500	m
F	2	/min
Actual Load	30.00	kg
%Capable	75	
VRM	1.000	m
DV	1.000	m
DV/min	2.00	m/min

		Lift	Lower
MAL (75% capable)		31.7 kg	33.7 kg
%Capable (of Actual Load)		79.8%	83.2%
	RL	82.6 kg	95.9 kg
Scale Factors (SF)	H_{SF}	1.000	1.000
	VRM_{SF}	0.994	0.994
	DV_{SF}	0.870	0.870
	F_{SF}	0.546	0.511
	Net_{SF}	0.472	0.442
	$\%Cap_{SF}$	0.814	0.795
	$Total_{SF}$	0.384	0.351

Figure A7 – Maximum Package (30kg), LM-MMH Lift & Lower chart for male

For the package having a mass of 30.00kg, a given truck (V TOP), and a width (W) of 0.25m, along with assumptions of a male lifter, and a lift frequency of 2 lifts per 1 minute with 75% of the population, maximum acceptable weight of lift and maximum acceptable weight of lower are calculated as 31.7kg and 33.7kg respectively. The actual load weight (30.00kg) is lower than those values (31.7kg and 33.7kg). Therefore, the lifting/lowering package task in a truck is considered safe.

Female Lift & Lower Case for normal mail tray:

Lift & Lower - Female

- Metric -

Inputs		
H	0.250	m
V_{TOP}	1.500	m
V_{BOTTOM}	0.500	m
F	3	/min
Actual Load	5.00	kg
%Capable	75	
VRM	1.000	m
DV	1.000	m
DV/min	3.00	m/min

	Lift	Lower
MAL (75% capable)	12.3 kg	12.5 kg
%Capable (of Actual Load)	99.5%	98.7%

Scale Factors (SF)	RL	34.9 kg	37.0 kg
	H_{SF}	0.935	0.935
	VRM_{SF}	0.952	0.952
	DV_{SF}	0.820	0.820
	F_{SF}	0.584	0.584
	Net_{SF}	0.426	0.426
	$\%Cap_{SF}$	0.825	0.793
	$Total_{SF}$	0.352	0.338

Figure A8 – Normal Mail Tray, LM-MMH Lift & Lower chart for female

For the mail tray having a mass of 5.00kg, a given truck (V TOP), and a width (W) of 0.25m, along with assumptions of a female lifter, and a lift frequency of 3 lifts per 1 minute with 75% of the population, maximum acceptable weight of lift and maximum acceptable weight of lower are calculated as 12.3kg and 12.5kg respectively. The actual load weight (5.00kg) is lower than those values (12.3kg and 12.5kg). Therefore, the lifting/lowering mail tray task in a truck is considered safe.

Female Lift & Lower Case for maximum package (30kg):

Lift & Lower - Female

- Metric -

Inputs		
H	0.250	m
V_{TOP}	1.500	m
V_{BOTTOM}	0.500	m
F	2	/min
Actual Load	30.00	kg
%Capable	75	
VRM	1.000	m
DV	1.000	m
DV/min	2.00	m/min

		Lift	Lower
MAL (75% capable)		13.0 kg	13.3 kg
%Capable (of Actual Load)		0.0%	0.5%
	RL	34.9 kg	37.0 kg
Scale Factors (SF)	H_{SF}	0.935	0.935
	VRM_{SF}	0.952	0.952
	DV_{SF}	0.820	0.820
	F_{SF}	0.620	0.620
	Net_{SF}	0.452	0.452
	$\%Cap_{SF}$	0.825	0.793
	$Total_{SF}$	0.373	0.359

Figure A9 – Maximum Package (30kg), LM-MMH Lift & Lower chart for female

For the package having a mass of 30.00kg, a given truck (V TOP), and a width (W) of 0.25m, along with assumptions of a female lifter, and a lift frequency of 2 lifts per 1 minute with 75% of the population, maximum acceptable weight of lift and maximum acceptable weight of lower are calculated as 13.0kg and 13.3kg respectively. The actual load weight (30.00kg) is greater than those values (13.0kg and 13.3kg). Therefore, the lifting/lowering package task in the truck is considered a risk.

RULA Score

Mail Tray (5.0kg) Lifting - RULA Score of 7

RULA Employee Assessment Worksheet

Task Name:

Date:

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

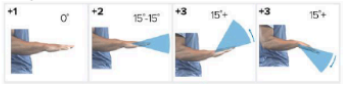
5 (4+1) — Upper Arm Score

Step 2: Locate Lower Arm Position:

1 — Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:



Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

1 — Wrist Twist Score

2 — Wrist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

5 — Posture Score A

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

0 — Muscle Use Score

+

Step 7: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

1 — Force / Load Score

=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in **Table C**.

6 — Wrist & Arm Score

Scores

Table A

Upper Arm	Lower Arm	Wrist Score 1 (Wrist Twist 1)	1 (2)	2 (1)	2 (2)	3 (1)	3 (2)	4 (1)	4 (2)
1	1	1	2	2	2	3	3	3
	2	2	2	2	2	3	3	3
	3	2	3	3	3	3	4	4
2	1	2	3	3	3	4	4	4
	2	3	3	3	3	4	4	4
	3	3	4	4	4	4	5	5
3	1	3	3	4	4	4	5	5
	2	3	4	4	4	4	5	5
	3	4	4	4	4	5	5	5
4	1	4	4	4	4	5	5	5
	2	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C

Wrist / Arm Score	Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

7 — **RULA Score**

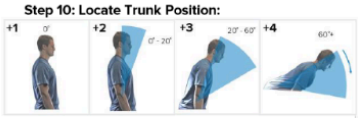
B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

4 — Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:



2 (1+1) — Trunk Score

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

1 — Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	8	8	
5	7	7	7	7	7	8	8	8	8	8	8	
6	8	8	8	8	8	8	9	9	9	9	9	

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B

5 — Posture B Score

+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

0 — Muscle Use Score

+

Step 14: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

1 — Force / Load Score

=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in **Table C**.

6 — Neck, Trunk, Leg Score

based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

Mail Tray (5.0kg) Lowering - RULA Score of 4

RULA Employee Assessment Worksheet

Task Name:

Date:

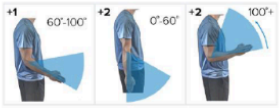
A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

3 — Upper Arm Score

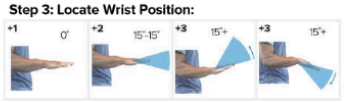
Step 2: Locate Lower Arm Position:



1 — Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:



Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

1 — Wrist Twist Score

2 — Wrist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

4 — Posture Score A

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

0 — Muscle Use Score

Step 7: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

1 — Force / Load Score

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in **Table C**.

5 — Wrist & Arm Score

Scores

Table A

Upper Arm	Lower Arm	Wrist Score 1 (Wrist Twist 1)	1 (Wrist Twist 2)	2 (Wrist Twist 1)	2 (Wrist Twist 2)	3 (Wrist Twist 1)	3 (Wrist Twist 2)	4 (Wrist Twist 1)	4 (Wrist Twist 2)
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C

Wrist / Arm Score	Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

4 — **RULA Score**

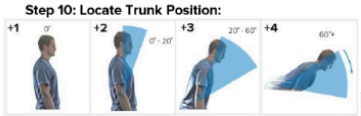
B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

2 — Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:



2 (1+1) — Trunk Score

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

1 — Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B

2 — Posture B Score

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

0 — Muscle Use Score

Step 14: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

1 — Force / Load Score

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in **Table C**.

3 — Neck, Trunk, Leg Score

based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

Package (30.0kg) Lifting - RULA Score of 7

RULA Employee Assessment Worksheet

Task Name:

Date:

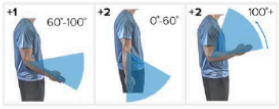
A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

5 (4+1)
Upper Arm Score

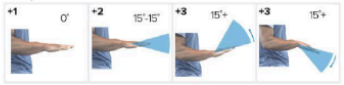
Step 2: Locate Lower Arm Position:



1
Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:



Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

1
Wrist Twist Score

2
Wrist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

5
Posture Score A

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

0
Muscle Use Score

+

Step 7: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

3
Force / Load Score

=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in **Table C**.

8
Wrist & Arm Score

Scores

Table A

Upper Arm	Lower Arm	Wrist Score 1 (Wrist Twist 1)	1 (Wrist Twist 2)	2 (Wrist Twist 1)	2 (Wrist Twist 2)	3 (Wrist Twist 1)	3 (Wrist Twist 2)	4 (Wrist Twist 1)	4 (Wrist Twist 2)
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C

Wrist / Arm Score	Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

7
RULA Score

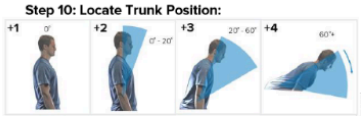
B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

4
Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:



2 (1+1)
Trunk Score

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

1
Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	8	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B

5
Posture B Score

+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>1 minute),
Or if action repeated occurs 4X per minute: +1

0
Muscle Use Score

+

Step 14: Add Force/Load Score
If load < 4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

3
Force / Load Score

=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in **Table C**.

8
Neck, Trunk, Leg Score

based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

Package (30.0kg) Lowering - RULA Score of 7

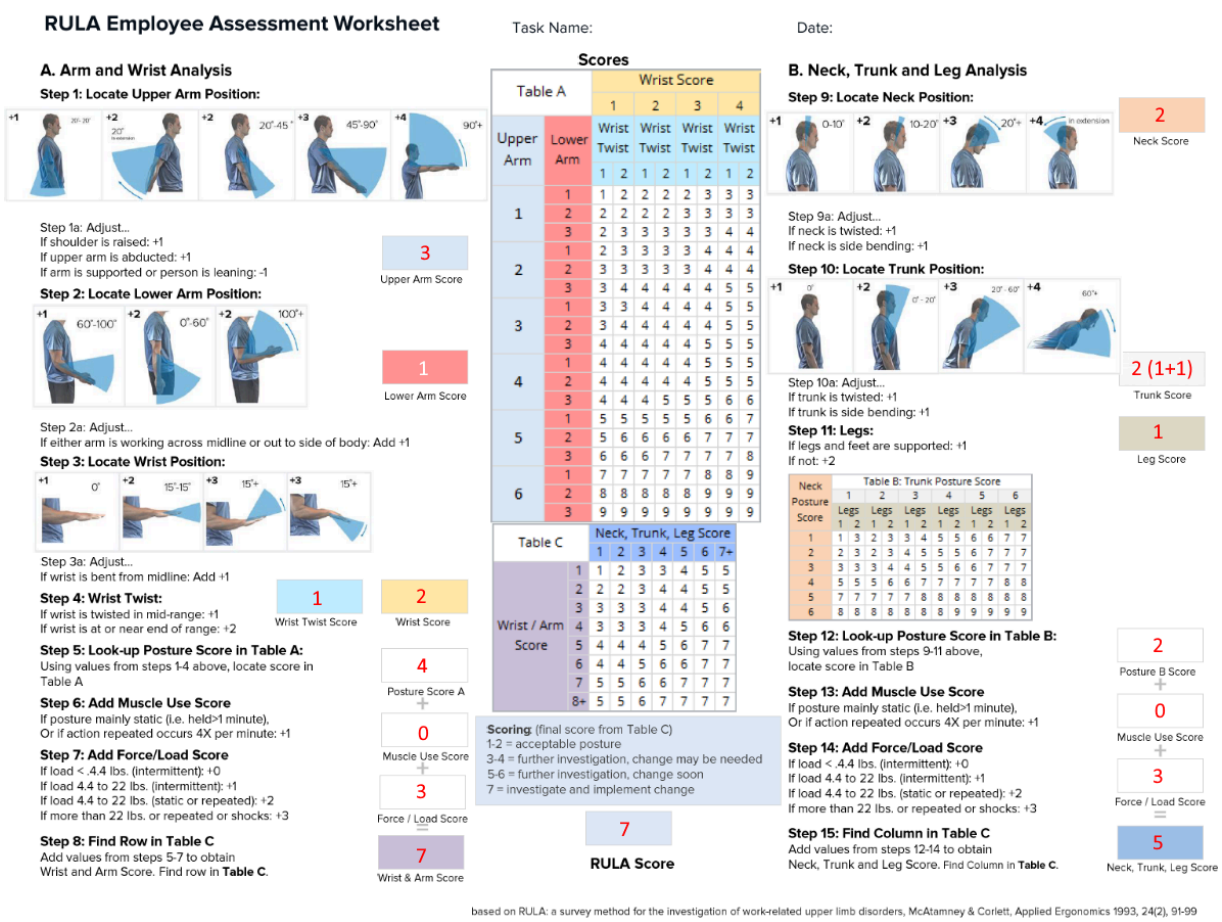


Figure A10 – RULA Score charts

A2. Lifting, Carrying and Lowering

NIOSH Lifting Equation

Table A1: inputs for NIOSH's lifting equation

	Description	**Value for Package (30 Kg)**	**Value for Mail (5 Kg)**
V	Vertical load distance from ground (cm)	Elbow length in normal position of 75 percentile males to ground= **111.60 cm.**	

		Elbow length in normal position of 75 percentile females to ground= **103.40 cm.**	
D	Vertical displacement of load (cm)	Vorigin - Vdestination= Truck bed to top of 4 steps = 66cm -50cm=**16 cm**	
W	Width of container	**50 cm**	**5 cm**
H	Horizontal load distance (cm)	H= 20 + W/2 (for V ≥ 25 cm) = **45 cm**	H= 20 + 5/2 (for V ≥ 25 cm) = **22.5 cm**
F	Lifting frequency (lifts/min & duration)	67 lifts/ (7hrs * 60 mins) = **0.16 lifts/min** for 7 hours	133 lifts/ (7hrs * 60 mins) = **0.32 lifts/min** for 7 hours
A	Asymmetric factor (degrees)	**0**	**0**
C	Coupling multiplier	**Fair, V≥ 75 cm**	**Good, V≥ 75 cm**

Table 5
Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Figure A11 - Frequency Multiplier value logic (Package in Red, Mail in Orange)

Table 6
Hand-to-Container Coupling Classification

GOOD	FAIR	POOR
1. 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].	1. 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].	1. Containers of less than optimal design or loose parts or irregular objects that are bulky, hard to handle, or have sharp edges [see note 5 below].
2. For loose parts or irregular objects, which are not usually containerized, such as castings, stock, and supply materials, a "Good" hand-to-object coupling would be defined as a comfortable grip in which the hand can be easily wrapped around the object [see note 6 below].	2. 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].	2. Lifting non-rigid bags (i.e., bags that sag in the middle).

Table 7
Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Figure A12 – Coupling Multiplier value logic (Package in Red, Mail in Orange)

Liberty Mutual Manual

Lift & Lower - Female

- Metric -

Inputs		
H	0.450	m
V_{TOP}	1.034	m
V_{BOTTOM}	0.500	m
F	0.16	/min
Actual Load	30.00	kg
%Capable	75	
VRM	0.767	m
DV	0.534	m
DV/min	0.09	m/min

		Lift	Lower
MAL (75% capable)		13.9 kg	14.1 kg
%Capable (of Actual Load)		0.1%	1.3%
Scale Factors (SF)	RL	34.9 kg	37.0 kg
	H_{SF}	0.675	0.675
	VRM_{SF}	0.980	0.980
	DV_{SF}	0.901	0.901
	F_{SF}	0.808	0.808
	Net_{SF}	0.481	0.481
	$\%Cap_{SF}$	0.825	0.793
	$Total_{SF}$	0.397	0.382

Figure A13 :LMM - Lifting and Lowering for Large Packages (30 kg) for Females

Lift & Lower - Male

- Metric -

Inputs		
H	0.450	m
V_{TOP}	1.116	m
V_{BOTTOM}	0.500	m
F	0.16	/min
Actual Load	30.00	kg
%Capable	75	
VRM	0.808	m
DV	0.616	m
DV/min	0.10	m/min

		Lift	Lower
MAL (75% capable)		35.3 kg	36.7 kg
%Capable (of Actual Load)		86.8%	87.5%
Scale Factors (SF)	RL	82.6 kg	95.9 kg
	H_{SF}	0.718	0.718
	VRM_{SF}	0.999	0.999
	DV_{SF}	0.915	0.915
	F_{SF}	0.801	0.734
	Net_{SF}	0.525	0.481
	$\%Cap_{SF}$	0.814	0.795
	$Total_{SF}$	0.427	0.383

Figure A14: LMM - Lifting and Lowering for Large Packages (30 kg) for Males

Lift & Lower - Female

- Metric -

Inputs		
H	0.200	m
V_{TOP}	1.034	m
V_{BOTTOM}	0.500	m
F	0.32	/min
Actual Load	2.00	kg
%Capable	75	
VRM	0.767	m
DV	0.534	m
DV/min	0.17	m/min

		Lift	Lower
MAL (75% capable)		19.4 kg	19.7 kg
%Capable (of Actual Load)		100.0%	99.9%
	RL	34.9 kg	37.0 kg
Scale Factors (SF)	H_{SF}	1.000	1.000
	VRM_{SF}	0.980	0.980
	DV_{SF}	0.901	0.901
	F_{SF}	0.762	0.762
	Net_{SF}	0.673	0.673
	$\%Cap_{SF}$	0.825	0.793
	$Total_{SF}$	0.555	0.533

Figure A15: LMM - Lifting and Lowering for Small Mail (2 kg) for Females

Lift & Lower - Male

- Metric -

Inputs		
H	0.250	m
V_{TOP}	1.116	m
V_{BOTTOM}	0.500	m
F	0.32	/min
Actual Load	2.00	kg
%Capable	75	
VRM	0.808	m
DV	0.616	m
DV/min	0.20	m/min

	Lift	Lower
MAL (75% capable)	45.5 kg	47.2 kg
%Capable (of Actual Load)	100.0%	99.9%

		Lift	Lower
	RL	82.6 kg	95.9 kg
Scale Factors (SF)	H_{SF}	1.000	1.000
	VRM_{SF}	0.999	0.999
	DV_{SF}	0.915	0.915
	F_{SF}	0.741	0.678
	Net_{SF}	0.677	0.620
	$\%Cap_{SF}$	0.814	0.795
	$Total_{SF}$	0.551	0.493

Figure A16: LMM - Lifting and Lowering for Small Mail (2 kg) for Males

Carry - Female

- Metric -

Inputs		
V	1.030	m
DH	10.000	m
F	0.16	/min
Actual Load	30.00	kg
%Capable	75	
DH/min	1.60	m/min

	Carry
MAL (75% capable)	15.9 kg
%Capable (of Actual Load)	0.5%

		Carry
	RL	28.6 kg
Scale Factors (SF)	V_{SF}	0.932
	DH_{SF}	0.962
	F_{SF}	0.735
	Net_{SF}	0.659
	$\%Cap_{SF}$	0.845
	$Total_{SF}$	0.556

Figure A17: LMM - Carrying Large Packages (30 kg) for Females

Carry - Female

- Metric -

Inputs		
V	1.030	m
DH	10.000	m
F	0.32	/min
Actual Load	2.00	kg
%Capable	75	
DH/min	3.20	m/min

		Carry
MAL (75% capable)		15.0 kg
%Capable (of Actual Load)		100.0%
Scale Factors (SF)	RL	28.6 kg
	V_{SF}	0.932
	DH_{SF}	0.962
	F_{SF}	0.692
	Net_{SF}	0.621
	$\%Cap_{SF}$	0.845
	$Total_{SF}$	0.524

Figure A18: LMM - Carrying Small Mail (2 kg) for Females

Carry - Male

- Metric -

Inputs		
V	1.100	m
DH	10.000	m
F	0.1600	/min
Actual Load	30.00	kg
%Capable	75	
DH/min	1.60	m/min

		Carry
MAL (75% capable)		25.6 kg
%Capable (of Actual Load)		56.6%
Scale Factors (SF)	RL	74.9 kg
	V_{SF}	0.774
	DH_{SF}	0.754
	F_{SF}	0.720
	Net_{SF}	0.420
	$\%Cap_{SF}$	0.813
	$Total_{SF}$	0.341

Figure A19: LMM - Carrying Large Packages (30 kg) for Males

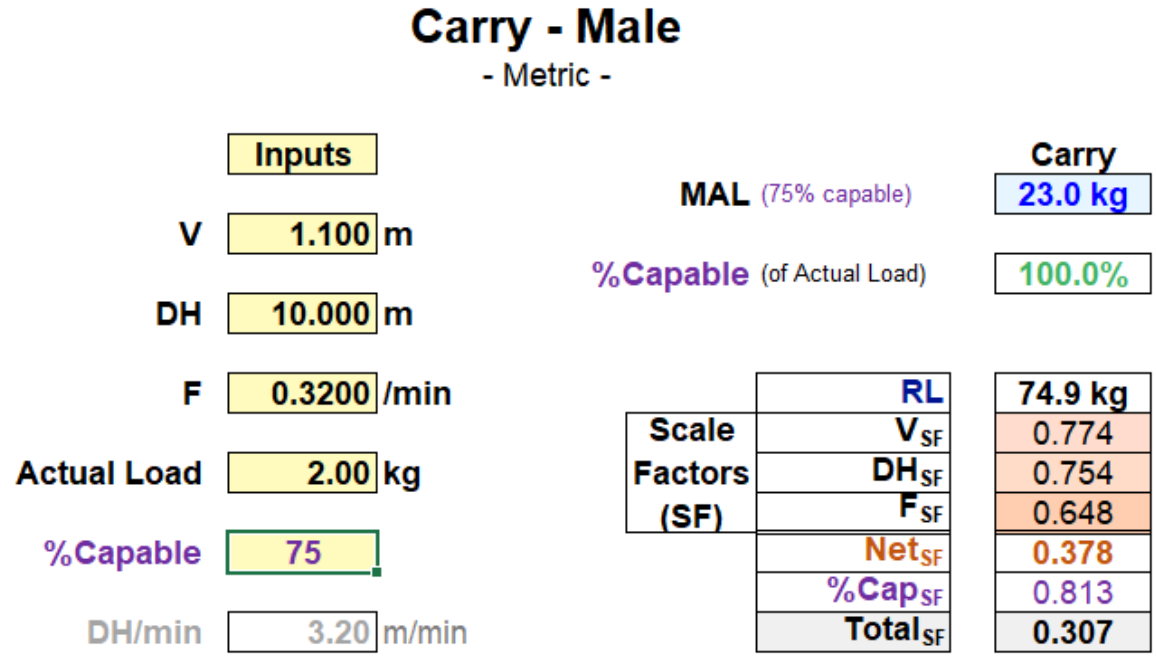


Figure A20: LMM - Carrying Small Mail (2 kg) for Males

Table A2 - Work Category based on Metabolic Rate in Watts [1]

Work Category	**Assigned Metabolic Rate (Watts)**	**Examples**
Rest	115	Sitting
Light	180	Sitting/driving/standing with light manual work with hands, standing and occasional walking
Moderate	300	Sustained moderate hand and arm work; moderate arm and leg/arm and trunk work; or light pushing/puling. Normal walking
Heavy	415	Heavy material handling, ie Intense arm and trunk work, carrying, shoeveling, manual sawing, pushing/pulling heavy loads; walking at a fast pace.
Very Heavy	520	Very intense activity at fast to maximum pace, ie Pick and shovel work

Table A3: Solar Irradiance based on Reported Cloud Cover [12]

Reported Cloud Cover	**Irradiance (W/m2)**
Sunny	990
Mostly Sunny, Partly Sunny/Cloudy or Scattered Clouds	980
Mostly Cloudy	710
Cloudy	250

Table A4: Clothing Adjustment Factor (CAF) [1]

Clothing Adjustment Factor (CAF) for TLV **(Values cannot be added when wearing multiple layers)**	
Clothing Type	WBGT Correction (°C)
Work clothes (long sleeve shirt and pants)	0
Cloth (woven material) coveralls	0
SMS (Spunbonded - Meltdown - Spunbonded) polypropylene coveralls	+ 0.5
Polyolefin coveralls	+ 1
Double-layer woven clothing	+ 3
Limited-use vapour-barrier coveralls	+ 11
Note: These values are not to be used for completely encapsulating suits. Coveralls assume only modest clothing is underneath, not a second layer of clothing.	

Table A5: CCOHS Summary of Control Measure for Heat Stress [12]

Summary of Control Measures for Heat Stress	
Methods of Control	Actions
Engineering controls	
Reduce body heat production	Mechanize tasks.
Stop exposure to radiated heat from hot objects	Insulate hot surfaces. Use reflective shields, aprons, remote controls.
Reduce convective heat gain	Lower air temperature. Increase air speed if air temperature below 35°C. Increase ventilation. Provide cool observation booths.
Increase sweat evaporation	Reduce humidity. Use a fan to increase air speed (movement).
Clothing	Wear loose clothing that permits sweat evaporation but stops radiant heat. Use cooled protective clothing for extreme conditions.
Administrative controls	
Acclimatization	Allow sufficient acclimatization period before full workload.
Duration of work	Shorten exposure time and use frequent rest breaks.
Rest area	Provide cool (air-conditioned) rest-areas.
Water	Provide cool drinking water.
Pace of Work	If practical, allow workers to set their own pace of work.
First aid and medical care	Develop and implement emergency procedures. Assign one person trained in first aid to each work shift. Train workers in how to recognize symptoms of heat exposure in themselves and others.

Table A6 - Wind Chill Hazard and Controls [5]

Wind Chill Hazards and What To Do			
Wind Chill	**Exposure Risk**	**Health Concerns**	**What to Do**
0 to -9	**Low risk**	• Slight increase in discomfort	• Dress warmly • Stay dry
-10 to -27	**Moderate risk**	• Uncomfortable • Risk of hypothermia and frostbite if outside for long periods without adequate protection.	• Dress in layers of warm clothing, with an outer layer that is wind-resistant. • Wear a hat, mittens or insulated gloves, a scarf and insulated, waterproof footwear. • Stay dry. • Keep active
-28 to -39	**High Risk**: exposed skin can freeze in 10 to 30 minutes	• High risk of frostnip frostbite: Check face and extremities for numbness or whiteness. • High risk of hypothermia if outside for long periods without adequate clothing or shelter from wind and cold.	• Dress in layers of warm clothing, with an outer layer that is wind-resistant • Cover exposed skin • Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear • Stay dry • Keep active

-40 to -47	**Very high risk**: exposed skin can freeze in 5 to 10 minutes (In sustained winds over 50 km/h, frostbite can occur faster than indicated.)	• Very high risk of frostbite: Check face and extremities for numbness or whiteness. • Very high risk of hypothermia if outside for long periods without adequate clothing or shelter from wind and cold.	• Dress in layers of warm clothing, with an outer layer that is wind-resistant. • Cover all exposed skin. • Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear. • Stay dry • Keep active.
-48 to -54	**Severe risk**: exposed skin can freeze in 2 to 5 minutes (In sustained winds over 50 km/h, frostbite can occur faster than indicated.)	• Severe risk of frostbite: Check face and extremities frequently for numbness or whiteness. • Severe risk of hypothermia if outside for long periods without adequate clothing or shelter from wind and cold.	• Be careful. Dress very warmly in layers of clothing, with an outer layer that is wind-resistant. • **Cover all exposed skin** • Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear. • **Be ready to cut short or cancel outdoor activities**. • Stay dry. • Keep active.

-55 and colder	**Extreme risk**: exposed skin can freeze in less than 2 minutes	• **DANGER!** Outdoor conditions are **hazardous.**	• **Stay indoors**.

Figure A21: Cost Analysis of Controls Inputs for Comparision of Injury Costs from 2020 - 2022 [29]