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Development of a NIOSH based software tool for musculoskeletal disorders

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Musculoskeletal disorders amongst workers performing manual lifting tasks have become a major challenge now a days. Such problems hamper productivity of any concern to a greater extent. Industrial experts and researchers have been devising ways and means to reduce such disorders and the National Institute of Occupational Safety and Health (NIOSH) agency lifting equation is one amongst such tools. NIOSH lifting equation has significantly enhanced the safety of the workers involved in manual lifting tasks. With this equation, a prior indication of musculoskeletal disorders can be obtained from the workers anthropometric details. However, till date there is no such tool available with which we can have recommendations to eliminate/reduce such disorders. In this paper an expert system on the basis of NIOSH equation has been developed to deal with the musculoskeletal problems amongst the workers involved in manual lifting tasks. The expert system is basically a computer programme developed to facilitate the use of NIOSH lifting equation. On the basis of lifting parameters, this equation computes recommended weight limit (RWL) and lifting index (LI). These outputs have been further analyzed by the programe to check existing working conditions against occupational hazards, and suggest recommendations for the safe working conditions.

Keywords: NIOSH, Recommended weight limit, Lifting index, Manual lifitng, Programme

1 Introduction

Automation still has not dominated the manual lifting in most of the Industries. The statistics show that manual material handling tasks are prevalent in one third of all industrial jobs[1]. While handling the material, the workers suffer from musculoskeletal disorders. Low back pain (LBP) has caused major musculoskeletal disorders along with financial losses to both employers and the employees. LBP frequently occurs in the places where lifting of materials is carried out manually[2]. The spinal loading has been found to enhance due to vibrations at the work place, repetitive work, heavy load lifting, static postures, frequent bending and twisting, *etc.*[3]. As per National Safety Council's Accident Facts[4], back injuries account for 32% of all worker compensation cases, thus declaring it to be the most common disabling occupational hazard in the United States. Another study reported disability due to LBP amongst 5.2 million individuals. Amongst these, 2.6 million people were temporarily disabled and rest were chronically disabled. The estimated expenses attributed to low-back pain vary from $16 billion to more than $50 billion[5]. LBP at the workplace resulted in huge medical expenses and it has been reported that 25% of all musculoskeletal injuries in United States were compensated. These injuries happened during manual tasks, and pain in the lower back was predominant. The Liberty Mutual Insurance Company in 1989 assessed lower back pain claims to be 33% of the total claims nearing to an expenditure[6] of $ 991,000,000. These claims are much more than indirect costs such as absenteeism, loss of productivity, holding workers, *etc.* Latest statistics projects low back pain to be one of the highest industrial injury taking place due to manual tasks and has an ongoing trend across the world. In United States, lower back pain has affected almost seventy million people, and seven million are adding to the lot on annual basis. In addition to this, tasks such as pulling, lowering, carrying, *etc.* has resulted in half a million injuries out of which 50–60% of the injuries are due to lower back pain[7]. The research of industrial injuries carried out in Korea at the workplace of Mando Machinery Corporation Ltd. reflects that during the first half of 1997, 46% industrial injury cases out of 1527 workers have been reported. Among the total injuries, 45.65% were attributed to low back

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pain, due to repeated manual material handling (MMH) tasks[8].

The National Institute of Occupational Safety and health (NIOSH) is the agency created by "The Occupational Safety and Health Act of 1970" in the U.S. Department of Health and Human Services. This agency ensures safe and healthy working environment for working persons, both male and female by providing them with updated information, and training related to occupational safety and health.

The problem of work-related back injuries was recognized by NIOSH and to deal with such problems, they had devised a tool for evaluating risks associated with manual lifting. This tool is basically an equation commonly known as NIOSH lifting equation[9-11]. NIOSH lifting equation (NLE) is used to assess two-handed lifting tasks with an objective of investigating growing problem of lower back injuries. This equation includes a lifting equation which is basically a multiplicative model with six inputs and two inputs. NLE gives Recommended Weight limit (RWL) and Lifting Index (LI) for various inputs like weight, height and distance of the object to be lifted, type of hand-object couplings, frequency of lifting, asymmetrical angles, *etc.*[12]. The objective of the equation is to inhibit or decrease the occurrence of lower back injuries among workers. The equation has also been reviewed and validated number of times[13-15]. Amongst the outputs of NLE, LI provides a comparative assessment of the physical stress related to manual lifting task *i.e.*, if the LI is higher than 1.0, it indicated high risk for lower back pain. The use of rapid upper limb assessment (RULA) and rapid entire body assessment (REBA) techniques has also aided researchers to locate awkward body postures and safeguard workers[16,17]. Researchers have also been developing new ways and means to deal with the similar industrial and societal problems. Various smart systems have been developed in order to safeguard and facilitate human labor[18-20].

In the present work, a computer programme has been developed with which the workers exposed to risk of musculoskeletal disorders can be assessed, and consequently safety of the workers is ensured by implementing the recommendations given by the computer programme. The programme accepts inputs as six variables which are basically the body measurements taken while lifting are being carried out by the worker. The processing is carried out by the programme and thus safe recommendations are made.

2 Methodology

The methodology adopted for the current paper comprises of the following steps:

(a) The NIOSH equation has been studied thoroughly along with its applications. The literature review is carried out, and the recommendations as suggested in the respective literature have been considered[21,22].

(b) Existing NIOSH based calculators were evaluated and their limitations were considered. Based upon these, the need for the Expert System (programme) was ascertained. The calculations of the RWL and LI is a laborious job when carried out manually as it consumes lot of time. It becomes more complicated when one has to change the task variables according to the place where worker is performing his/her lifting job, followed by recalculation of the RWL and LI. Thus considering these limitations, the following programme has been developed.

(c) Few NIOSH calculators are also available on internet but they too have limitations as follows

- Lack of range of task variables i.e they are left with very few options for the task variables.
- Suggest only the output value without any interpretations / recommendations.

(d) There are benefits offered by the proposed system. The developed programme:

- Not only gives the output but also suggests safe and unsafe values of various lifting parameters.
- Clearly specifies the changes to be carried out in respective task variables if found unsafe in order to safe guards workers from any disorder.
- Is absolutely user friendly as one has just to enter the task variables taken at the origin and destination of the lift and rest of the calculation is done by the programme.
- The programme suggests recommendations which if implemented will definitely result in safe working environment.
- The architecture and the flowchart of the programme has been developed and discussed in the following section.
- The programming language used for the development of the programme is C++ as it is readily available and easily understood.

3 Design

The design phase comprises of the following:

(a) Architecture of the programme

(b) Algorithm of the programme
(c) Flowchart of the programme

3.1 Architecture of the programme

The basic architecture of the computer programme is as shown in Fig. 1. The task variables such as horizontal reach, vertical distance, frequency *etc.* measured at the time of the lifting, both at origin as well as the destination serve as the input which is to be given by the user. The programme then calculates the multipliers for each of the task variable using various tables and equations as mentioned in the NIOSH work practice guide[20]. These multipliers then form the basis for the NIOSH lifting equation which finally calculates and displays RWL and the LI.

The programme further checks if the LI calculated at the origin as well as the destination is safe or not. If it is safe then the same is displayed and if the results are unsafe, the programme further compares each of the task variables given by the user with the safe values as given in the NIOSH work practice guide[20-23]. The task variables which are unsafe are displayed along with the changes as recommended by the programme. The user on implementing these recommendations will get safe lifting index and thus safe working environment.

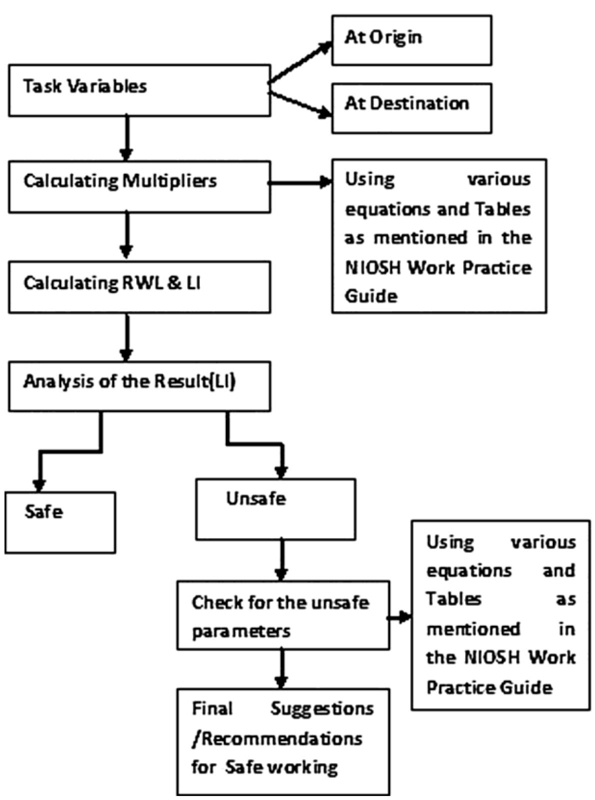


Fig. 1 — Architecture of the programme.

The programme has been developed in C++ language and is DOS based. It is very easy to use, as at every step it asks user to input the data and results are displayed in such a way so that they are easily interpreted by the user.

3.2 Algorithm of the programme

This section describes the algorithm of the developed computer programme and below mentioned are the steps of the algorithm**:**

1. Start of the programme.
2. Declare and initialize various variables and constants involved such as LC, H1, H2, V1, V2, A1, A2, *etc.*
3. Declare various functions to be included in the programme
4. Get the input from the user for the various task variables for both, at origin and at destination of the lift.
5. Corresponding to the task variables, call the respective functions to get the value for various multipliers and display the same.
6. Calculate the values of RWL and LI and display the same.
7. Check for the LI , at origin and at destination of the lift and display the information if it is safe.
8. If check performed in step vii is not safe, then again check for the LI at origin only.
9. If LI at origin is safe then skip the Step x.
10. If LI at origin is unsafe then check for the safe limits for each task variable and display the respective recommendations.
11. If LI at destination is safe then skip the Step xii.
12. If LI at destination is unsafe then check for the safe limits for each task variable and display the respective recommendations.
13. If LI at origin and destination is safe then skip Step xiv.
14. If LI at origin or destination is unsafe, then check for frequency of lifting, coupling and duration of lifting and make the respective recommendations.
15. Enquire from the user whether he/she wants to continue.
16. If user enters ‘Yes’, then repeat all the steps starting from Step 4.
17. If user enters ‘NO’, then exit the programme.

3.3 Flow chart for the programme

Based upon the algorithm as discussed above, flowchart has been prepared as shown in Fig. 2. The computer programme has been developed based

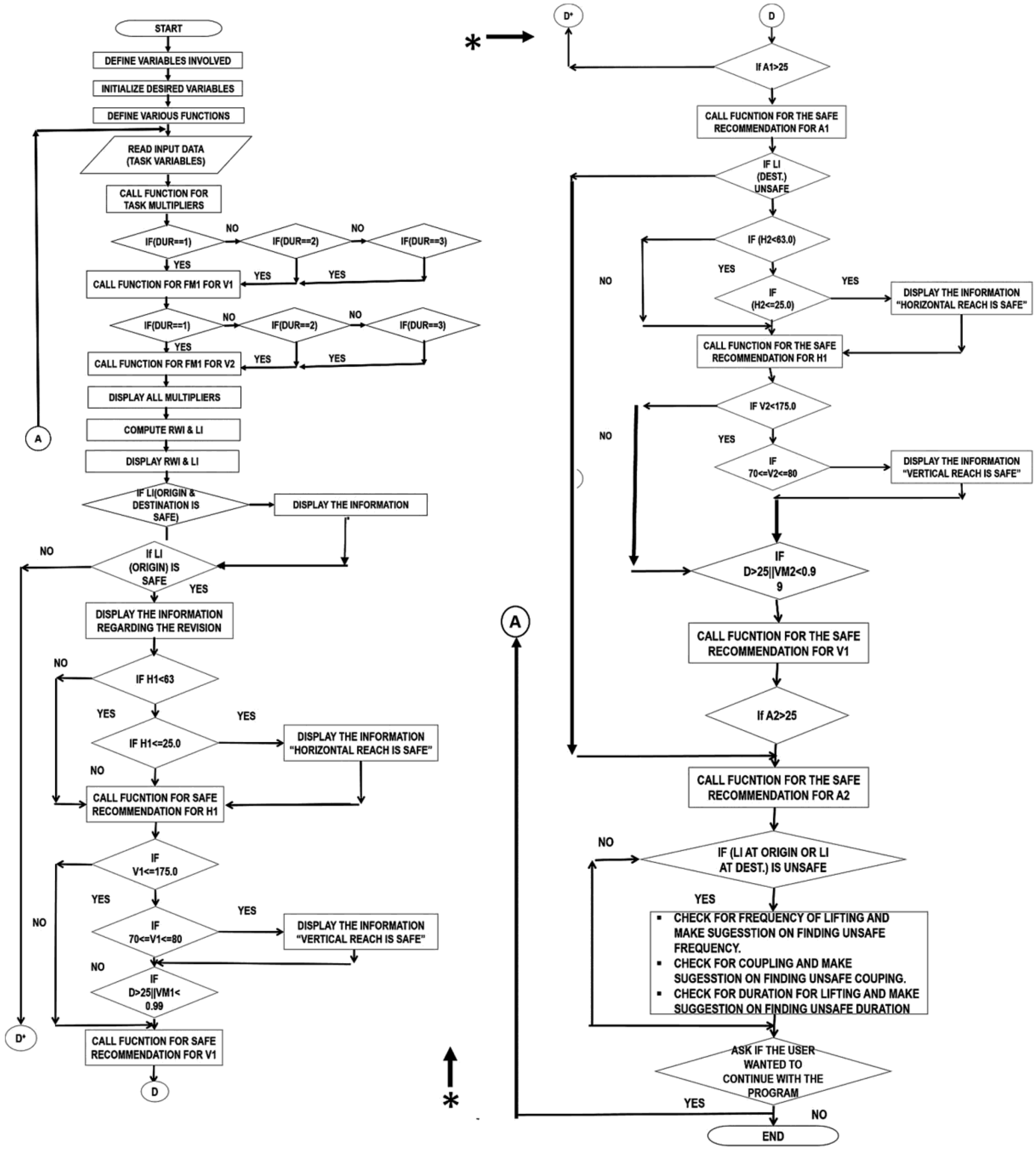


Fig. 2 — Flow chart of the programme.

upon the flowchart, and the output of the programme is discussed in the succeeding section.

4 Results and Discussion

4.1 Testing

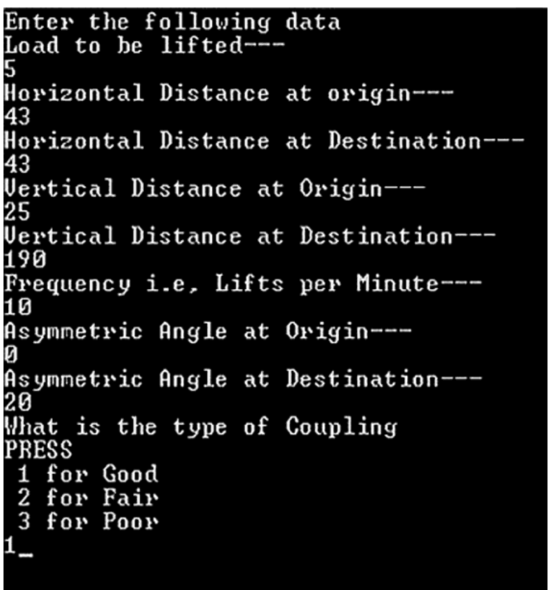
The programme developed was finally tested for its authentication. Few sample readings were taken on the site and thereafter manual calculations for the same were done for RWL and LI. The same readings were fed to the programme and the RWL and LI were obtained. These results were then compared with the manually calculated results using tables as mentioned in NIOSH work practice guide[23]. It was ensured that the results obtained from the programme are accurate and reliable as the programme incorporates the maximum flexibility.

4.2 Program results

The data taken from a worker carrying out manual lifting is as mentioned in Table 1. The input data was fed to the programme and the results were then

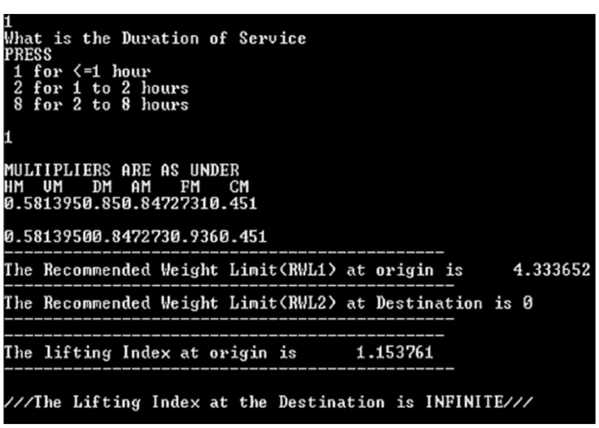
Table 1 — Input parameters for NIOSH equation.

S.No	Variable description	Value
1	Horizontal Task Variable at Origin of the Lift (H1)	43cm
2	Horizontal Task Variable at Destination of the Lift (H2)	43 cm
3	Verticle Task Variable at Origin of the Lift (V1)	25cm
4	Verticle Task Variable at Destination of the Lift (V2)	190cm
5	Asymmetric Angle at the Origin (A1)	0
6	Asymmetric Angle at the Destination (A2)	20
7	Verticle Lift (D)=V2-V1	165cm
8	Frequency of Lifting (F)	10 lifts/min
9	Duration of the work (Dur)	<1 hour
10	Type of Coupling (C)	Good



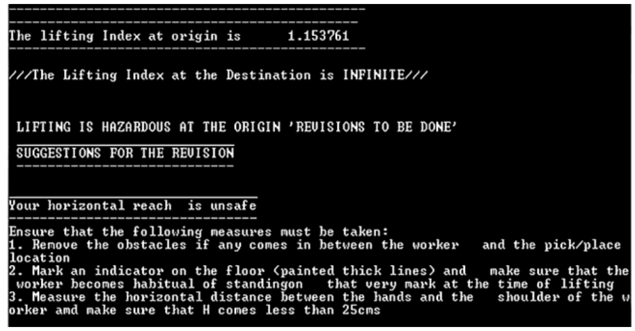
```
Enter the following data
Load to be lifted---
5
Horizontal Distance at origin---
43
Horizontal Distance at Destination---
43
Vertical Distance at Origin---
25
Vertical Distance at Destination---
190
Frequency i.e, Lifts per Minute---
10
Asymmetric Angle at Origin---
0
Asymmetric Angle at Destination---
20
What is the type of Coupling
PRESS
 1 for Good
 2 for Fair
 3 for Poor
1_
```

Fig. 3(a) — Input data.



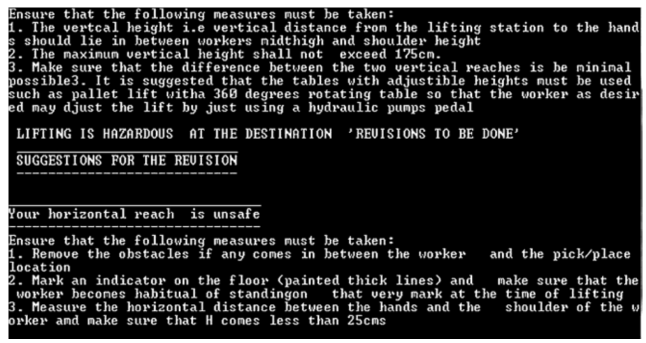
```
1
What is the Duration of Service
PRESS
 1 for <=1 hour
 2 for 1 to 2 hours
 8 for 2 to 8 hours

1

MULTIPLIERS ARE AS UNDER
HM  VM   DM  AM   FM   CM
0.5813950.850.84727310.451

0.58139500.8472730.9360.451
--------------------------------------------
The Recommended Weight Limit(RWL1) at origin is     4.333652
---------------------------------------------
The Recommended Weight Limit(RWL2) at Destination is 0
---------------------------------------------
--------------------------------------------
The lifting Index at origin is      1.153761
---------------------------------------------

///The Lifting Index at the Destination is INFINITE///
```

Fig. 3(b) — Multiplier calculations.



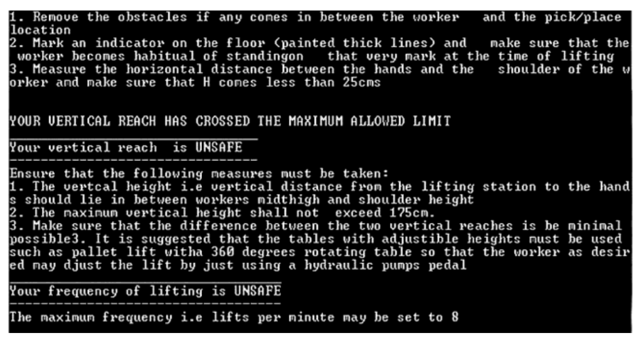
```
---------------------------------------------
--------------------------------------------
The lifting Index at origin is      1.153761
---------------------------------------------

///The Lifting Index at the Destination is INFINITE///


 LIFTING IS HAZARDOUS AT THE ORIGIN 'REVISIONS TO BE DONE'
 SUGGESTIONS FOR THE REVISION
 ----------------------------


Your horizontal reach  is unsafe
--------------------------------
Ensure that the following measures must be taken:
1. Remove the obstacles if any comes in between the worker   and the pick/place
location
2. Mark an indicator on the floor (painted thick lines) and   make sure that the
 worker becomes habitual of standingon   that very mark at the time of lifting
3. Measure the horizontal distance between the hands and the   shoulder of the w
orker amd make sure that H comes less than 25cms
```

Fig. 3(c) — Recommendations for unsafe lifting at the origin.



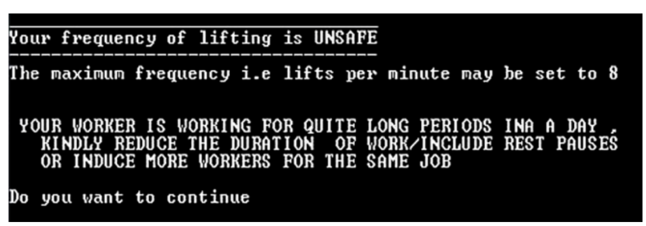
```
Ensure that the following measures must be taken:
1. The vertcal height i.e vertical distance from the lifting station to the hand
s should lie in between workers midthigh and shoulder height
2. The maximum vertical height shall not  exceed 175cm.
3. Make sure that the difference between the two vertical reaches is be minimal
possible3. It is suggested that the tables with adjustible heights must be used
such as pallet lift witha 360 degrees rotating table so that the worker as desir
ed may djust the lift by just using a hydraulic pumps pedal

 LIFTING IS HAZARDOUS  AT THE DESTINATION  'REVISIONS TO BE DONE'

 SUGGESTIONS FOR THE REVISION
 ----------------------------


Your horizontal reach  is unsafe
--------------------------------
Ensure that the following measures must be taken:
1. Remove the obstacles if any comes in between the worker   and the pick/place
location
2. Mark an indicator on the floor (painted thick lines) and   make sure that the
 worker becomes habitual of standingon   that very mark at the time of lifting
3. Measure the horizontal distance between the hands and the   shoulder of the w
orker amd make sure that H comes less than 25cms
```

Fig. 3(d) — Recommendations for unsafe lifting at the origin/ destination.



```
1. Remove the obstacles if any comes in between the worker   and the pick/place
location
2. Mark an indicator on the floor (painted thick lines) and   make sure that the
 worker becomes habitual of standingon   that very mark at the time of lifting
3. Measure the horizontal distance between the hands and the   shoulder of the w
orker amd make sure that H comes less than 25cms


YOUR VERTICAL REACH HAS CROSSED THE MAXIMUM ALLOWED LIMIT

Your vertical reach  is UNSAFE
--------------------------------
Ensure that the following measures must be taken:
1. The vertcal height i.e vertical distance from the lifting station to the hand
s should lie in between workers midthigh and shoulder height
2. The maximum vertical height shall not  exceed 175cm.
3. Make sure that the difference between the two vertical reaches is be minimal
possible3. It is suggested that the tables with adjustible heights must be used
such as pallet lift witha 360 degrees rotating table so that the worker as desir
ed may djust the lift by just using a hydraulic pumps pedal

Your frequency of lifting is UNSAFE
-----------------------------------
The maximum frequency i.e lifts per minute may be set to 8
```

Fig. 3(e) — Recommendations for lifting at the destination.



```
Your frequency of lifting is UNSAFE
-----------------------------------
The maximum frequency i.e lifts per minute may be set to 8


 YOUR WORKER IS WORKING FOR QUITE LONG PERIODS INA A DAY ,
   KINDLY REDUCE THE DURATION  OF WORK/INCLUDE REST PAUSES
   OR INDUCE MORE WORKERS FOR THE SAME JOB

Do you want to continue
```

Fig. 3(f) — Input for start and stop of the programme.

obtained which have been shown in screen shots obtained as an output of the executed programme from Fig. 3(a-f).

Figure 3a shows the first screen after execution of the programme where in it asks for various input data as mentioned in Table 1. Once the data is entered, the programme calculated different multipliers along with

Table 2 — Comparison of results.

Multipliers	Tables	Programme
HM1	0.58	0.581395
HM2	0.58	0.581395
VM1	0.85	0.85
VM2	0.0	0.0
AM1	1.0	1.0
AM2	0.94	0.936
DM	0.85	O.847
FM	0.45	0.45
CM	1.0	1.0
RWL(ORIGIN)==	4.38	4.334
RWL(DESTN)==	0.0	0.0
Lifting Index(Origin)=	5/4.38=1.14(unsafe)	5/4.334=1.15
Lifting Index(Destn)=	5/0=∞	(unsafe5/0=∞

RWL and LI as shown in Fig. 3(b-e) displays the safe and unsafe lifting index (LI), and based upon unsafe LI, it identifies the input parameters resulting in unsafe index. Followed by this, the programme also suggests safe recommendations which have to be incorporated on the site in order to create safe working environment. Figure 3f prompts user to select an option if he/she wants to continue or not.

5 Conclusions

The programme developed for the NIOSH lifting equation would prove to be the best tool for the wide spread applicability of the equation as it gives reliable results along with solution for the problem, if any. On the basis of output given by the computer programme, a safe lifting can be ensured. Depending upon the application and worksite conditions, various input parameters like horizontal distance (H), vertical location (V) , frequency of lifting *etc*. are determined which are further used for computing lifting index which forms the criterion for creating safe work environment. The programme is tested for accuracy by comparing its results with theoretical calculations carried out using data for multipliers from standard tables as mentioned in NIOSH work practice guide. The comparison has shown negligible deviation in the results as shown in Table 2.

On the basis of lifting index, computer programme suggests recommendations/alternatives for various unsafe conditions, thereby making work environment safe. The user needs not to refer tables and go for lengthy exercises to find out the solutions to be implemented in order to safe guard the worker. This programme thus is a tool in the hands of the authorities to safe guards their workers so that overall productivity increases.

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