EVALUATION AND PRIORITIZATION OF FACTORS AFFECTING ENERGY EXPENDITURE OF WORKERS ENGAGED IN MANUAL MATERIAL HANDLING USING ANALYTICAL HIERARCHY PROCESS

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ABSTRACT

The present study aimed to evaluate energy expenditure of workers engaged in a manual material handling task .The various factors/sub factors influencing energy expenditure with physical impact on the human body were prioritized in terms of weight values by using the Analytical Hierarchy Process. The study included a sample of sixty male workers with a mean age ± SD of 40.34 ± 7.65, data with respect to their job activity and physical characteristics were collected using a validated questionnaire. The results showed an average working heart rate ± SD of 124.5±12.24 beats/min and average energy expenditure ± SD of 3370.33 ± 283.86 kcal; these are clear indicators of strenuous activity. The results of the AHP evaluation showed physical workload (PW) as the most important factor followed by physical work capacity (PWC), type of activity (TOA), organizational factors (OF) and personal factors (PF) with weight values of 0.454139, 0.252781, 0.129274, 0.125318 and 0.038488 respectively. The study concluded with prioritization of various factors contributing to a high rate of energy expenditure which may lead to overexertion and musculoskeletal injuries. The findings indicated an utmost

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need to redesign job content with the addition of some periods of break time in order for the body to recover from the excessive energy expenditure.

Keywords: Manual Material Handling (MMH); Total daily energy expenditure (TDEE); Analytical Hierarchy Process (AHP)

1. Introduction

Manufacturing is the greatest need of a developing country to support economic growth, and involves a number of manual material handling (MMH) tasks performed by blue collar workers (Marras, W. S., Cutlip, R. G. et al., 2009). These tasks may include activities like lifting, carrying, pulling, pushing or moving a supporting load by workers for particular period of time. If such tasks are performed repetitively with non-ergonomic conditions they may cause either temporary or permanent injury (Rossi, D., Bertoloni, E. et al., 2013). Repetitive tasks with rigorous effort cause overexertion due to a high rate of energy expenditure which ultimately leads to muscular skeletal disorders (MSDs) in workers (Kee, D., & Seo, S. R., 2007). Moreover, it increases absenteeism and the rate of compensation to workers under such conditions (Kee, D., & Seo, S. R., 2007).The dynamic MMH tasks demand a high level of energy which may decrease body strength and result in consequent MSDs (Waters, T. R., Putz-Anderson et al., 1993). The rate of energy expenditure depends upon the type of MMH occupation (light, moderate, heavy, very heavy or extremely heavy) as well as other daily activities performed (Indian Council of Medical Research, 2010). The World Health Organization (WHO) has adopted a factorial technique to estimate energy requirements depending upon body weight to predict a person's basal metabolic rate (BMR). At the same time physical activity level (PAL) is determined using physical activity ratio (PAR) values, which are further determined from daily activities to calculate total daily energy expenditure (Indian Council of Medical Research, 2010).

In developing countries like India, human labor has been engaged as a load transfer device repetitively for loading and unloading activities from conveyor to pallets, carts or directly into trucks/wagons. In such cases, human labor is necessary due to a lack of automation which if used would result in a high cost investment for industries. Very few studies have been found that focus on energy expenditure of workers engaged in MMH tasks (Puttewar, A. S., & Jaiswal, S. B., 2014; Ismaila, S., Oriolowo, K.et al., 2012; Nawi, N. M., Yahya, A., et al., 2012; Li, K. W., Yu, R. et al., 2009; Pradhan, C. K., Thakur, S., et al., 2007). Even fewer studies have reported on Indian labor and the influence of energy expenditure on the human body due to MMH activities as part of a worker's occupation (Pradhan, C. K., Thakur, S. et al., 2007).

In the present study, the repetitive manual material handling activity considered was in the baggage section of a fertilizer firm, where laborers are engaged in loading/unloading 50 kg bags of urea from a running conveyor to trucks/wagons 7.5 meters away (approximately 8 steps). A single break time period of 45 minutes was given to workers during an 8 hour working shift. This MMH activity puts a forceful exertion on the human body that leads to a high rate of energy expenditure that causes over exertion and MSDs. A number of factors affecting energy expenditure are still unexplored, so there is a need to identify and prioritize these factors. Hence, the present study is carried out in order to evaluate and prioritize various factors affecting the rate of energy expenditure using the

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Analytical Hierarchy Process (AHP). This will help determine necessary measures for combating the effects of high energy expenditure.

2. Methods

The methodology used for investigation is described in Figure 1 as shown below:

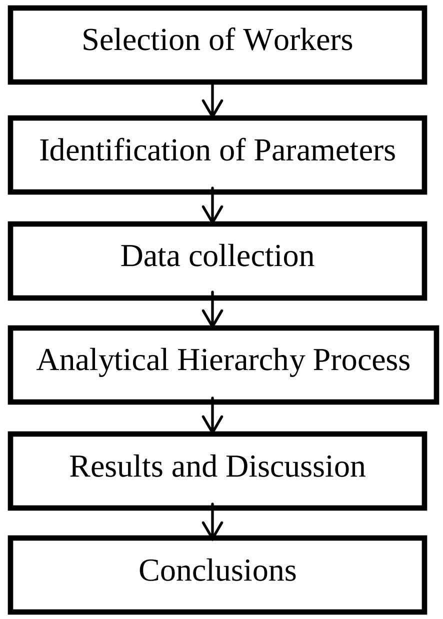

Figure 1. Block diagram of methodology

2.1. Selection of workers

A sample of sixty male workers at a fertilizer firm was selected using non probability convenience sampling. All of the workers were performing manual lifting and carrying activities without any aid from mechanized machinery/devices. A suitable questionnaire was devised for collecting data pertaining to age, height, weight, body mass index and energy expenditure of the workers. The questionnaire was pre-tested and validated using opinions of experts and chron bach alpha (0.78).

2.2 Physical workload

The physical workload of the job activity was classified based upon the observed heart rate which was obtained using a Polar Heart Rate monitor. Activities were categorized as light, moderate, heavy, very heavy or extremely heavy as mentioned in Table 1 (Astrand, P. O., 2003).

Table 1
Classification of physical workload

Physical Workload	**Heart rate (Beats/Min)**
Light Work	Up to 90
Moderate Work	90-110
Heavy Work	110-130
Very Heavy Work	130-150
Extremely Heavy Work	150-170

2.3 Total daily energy expenditure (TDEE)

Each participant was interviewed using a questionnaire and information was collected about time spent in various physical activities throughout a day. Further, total daily energy expenditure (TDEE) was calculated from observed data by following a standardized procedure given by the Indian Council of Medical Research (2010). Total daily energy expenditure is calculated as:

$$\text{TDEE (kcal)} = \text{Predicted BMR} \times \text{PAL}$$

Where BMR is basal metabolic rate i.e. amount of energy expended daily by humans at rest and calculated as follows:

$$\text{Equation for prediction of BMR (kcal/24h): } 10.9 \times \text{Body Weight (kg)} + 833$$

Where PAL is physical activity level i.e. a person’s total daily energy expenditure in a 24 hour period divided by Basal Metabolic Rate (BMR), which is calculated as follows:

$$\text{PAL} = \frac{\text{TDEE (in 24 hr)}}{\text{BMR}}$$

2.4 Analytical Hierarchy Process

The Analytical Hierarchy Process is a decision making tool applied under various complex situations where a number of factors and sub-factors affect the goal simultaneously (Singh, H., & Kumar, R., 2013; Badri, M. A., 2001). The result gives priorities to every factor/sub factor with some weight value by following a systematic methodology (Figure 2). A standardized procedure has been given by Saaty (1990).

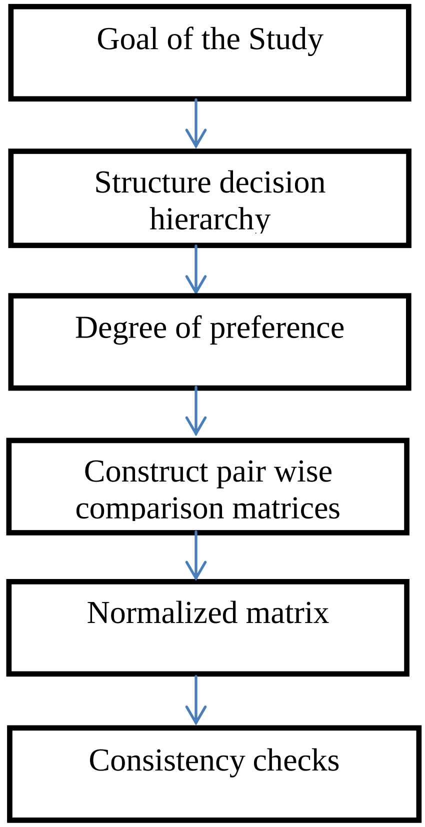

Figure 2. Systematic methodology of AHP (Saaty, T. L., 2008)

2.4.1 Goal of the study

The goal of the present study is to evaluate various factors/sub factors influencing the total energy expenditure of workers engaged in a manual material handling activity on the basis of weight values.

2.4.2 Structure of hierarchy

A three-level relative hierarchy model was structured. Level 1 refers to the overall objective, level 2 is composed of five main criteria such as physical workload (PW), type of activity (TOA), physical work capacity (PWC), organizational factors (OF) and personal factors (PF) and level 3 is made up of 23 sub-criteria as shown in Figure 3.

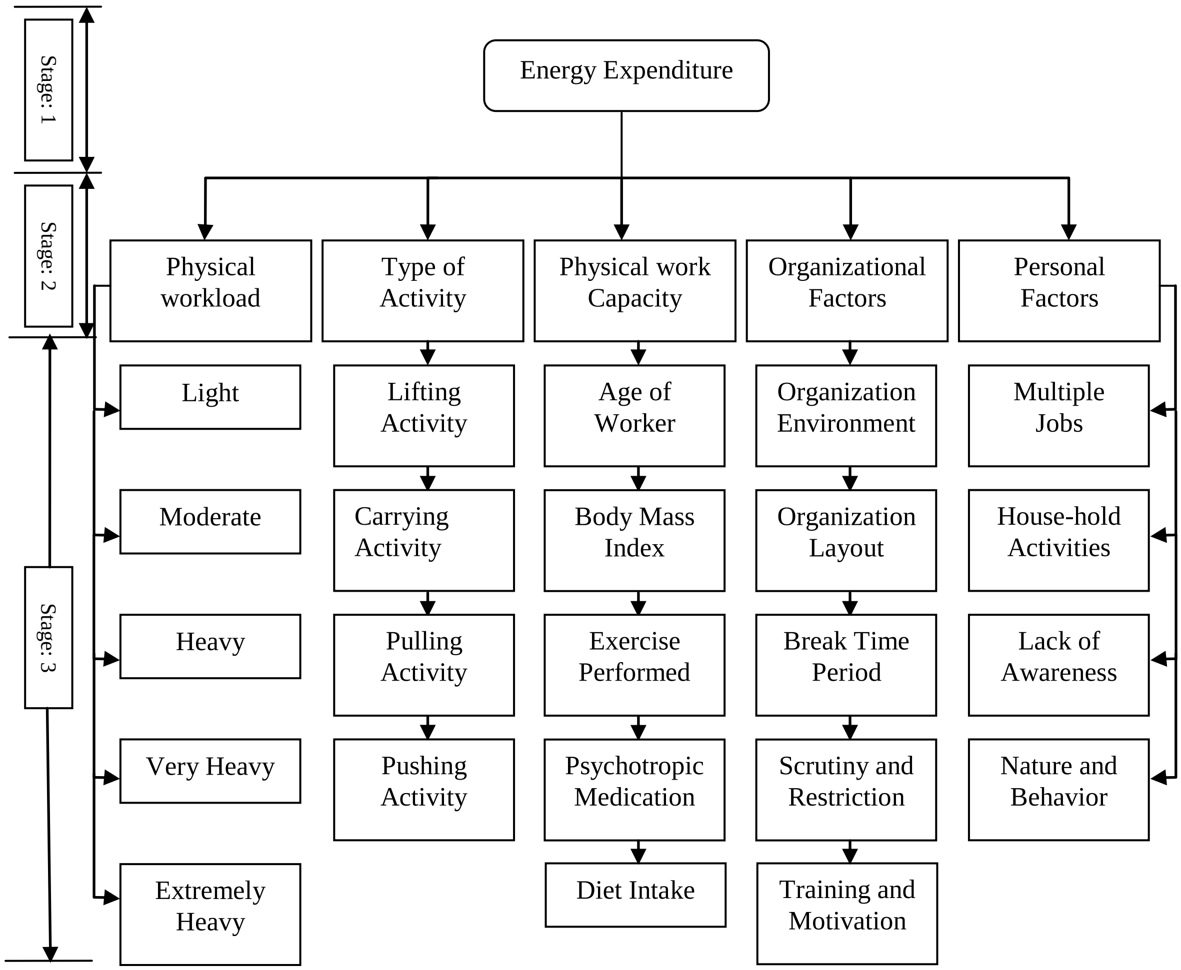

Figure 3. Three-level hierarchy model

2.4.3 Degree of preference

A 1-9 point scale was used in the pair wise comparison which is a standard procedure used to make decisions in a quantified form. This is shown in Table 2.

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Table 2
Degree of preference (Saaty, T. L., 1990)

Value	Judgment	Description
1	Equal	Two alternatives share the same level of importance
3	Moderate	Experience and judgment favors one alternative with respect to the other in little measure
5	Strong	Experience and judgment strongly favor one attribute over another
7	Very strong	Experience and judgment tell that one alternative is much more important than the other
9	Extreme	The difference of importance is extreme
2,4,6,8	Intermediate values	Used if more precision is needed

2.4.4 Pair-wise comparison

The importance of i^{th} sub-objective was compared with j^{th} sub-objective. In the current study 23 sub-objectives were considered as shown in Figure 3 above.

2.4.5 Normalized matrix of different sub-objectives

After a pair-wise comparison matrix is obtained, the next step is to divide each entry in a column by the sum of entries in the column to get the value of a normalized matrix. The values of a normalized matrix r_{ij} are calculated by using the following formula:

$$r_{ij}=\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

The average of the elements in each row gives an estimate of relative weights of sub-objectives being compared. Thus, the approximate priority weights (W1, W2 . . . Wj) for each sub-objective are computed as given in the formula below:

$$\mathrm{W_j} = \frac{1}{n} \times \sum_{i=1}^{n} a_{ij}$$

2.4.6 Consistency Index

A consistency check is performed using a consistency index (CI), which is calculated by the following expression:

$$\mathrm{CI} = \lambda_{\max} - \frac{\mathrm{n}}{(\mathrm{n}-1)}$$

After a CI value, a consistency ratio (CR) is calculated by using the following formula:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

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Table 3
Random index values

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Where: λ_{max} is the maximum Eigen value, n is dimensional matrix.
Generally, if CR is less than 0.1 then judgments are consistent and acceptable, where random consistency index (RI) is fixed for every dimensional matrix and the same is selected from Table 3 as given above.

3. Results

As per the qualitative data, the results revealed that the mean age±SD of the sample was 40.34 ±7.65 years with the minimum experience of two years in the same occupation. The majority of workers (65%) were illiterate or under middle standard of education. The demographic parameters are exhibited in Table 4. In addition, a working heart rate and total daily energy expenditure was recorded as an average of 124.5 ± 12.24 beats/min and 3369.78±284.86 kcal respectively.

Table 4
Physical characteristic of the workers

Physical characteristic	**Mean and Standard Deviation**		
	30-40yrs	**40-50yrs**	**50-60yrs**
Height (cm)	168.66 ± 7.45	160.34 ± 4.04	165.25 ± 11.18
Weight (kg)	70.8 ± 8.13	69.7 ± 7.81	70.25 ± 5.55
BMI (kg/m$^{2)}$	25.29 ± 1.50	26.33 ± 2.28	26.42 ± 2.16
Working heart rate (beats/min)	133.5 ± 12.54	124.6 ±13.72	115.4 ± 10.49
TDEE (kcal)	3557.3 ± 318.50	3311.30 ± 257.06	3240.74 ±279.03

3.1 Analytical Hierarchy Process

A number of factors and sub factors were identified based on the literature and expert advice. Subsequently, the AHP was applied to construct a hierarchy for the identification and prioritization of main and sub factors (Figure 3). Physical work load (PWL) was found to be the most significantly influencing factor followed by physical work capacity (PWC), type of activity (TOA), organizational factors (OA) and personal factors (PF) with respect to the objective (Table 5-10).

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Table 5
Paired comparison matrix level 1 with respect to objective

	PWL	**TOA**	**PWC**	**OF**	**PF**	**Weigh t**
PWL	1	2	3	5	9	0.454139
TOA	0.5	1	1/3	½	5	0.129274
PWC	1/3	3	1	3	5	0.252781
OF	1/5	2	1/3	1	3	0.125318
PF	1/9	1/5	1/5	1/3	1	0.0384886

λ_{max} = 5.38165, CI= 0.0954129, For n=5, CR= 0.0851900 = 8.52% < 10% (acceptable)

Table 6
Paired comparison matrix level 2 with respect to Factor 'PWL'

	Light	**Moderate**	**Heavy**	**Very heavy**	**Extremely heavy**	**Weight**
Light	1	2	1/5	½	¼	0.0861751
Moderate	1/5	1	1/5	1/3	¼	0.0606928
Heavy	5	5	1	3	2	0.426509
Very heavy	2	3	1/3	1	½	0.154824
Extremely heavy	4	4	1/5	2	1	0.271799

λ_{max} = 5.08528, CI= 0.0213193, For n=5, CR= 0.0190350 = 1.90% < 10% (acceptable)

Table 7
Paired comparison matrix level 2 with respect to Factor 'TOA'

	Lifting	**Carrying**	**Pulling**	**Pushing**	**Weight**
Lifting	1	1/5	7	3	0.226462
Carrying	5	1	9	5	0.629104
Pulling	1/7	1/9	1	1/3	0.0423596
Pushing	1/3	1/5	3	1	0.102074

λ_{max} = 4.21714, CI= 0.0723807, For n=4, CR= 0.080423 = 8.04% < 10% (acceptable)

Table 8
Paired comparison matrix level 2 with respect to factor PWC

	Age	**BMI**	**Exercise**	**Psychotropic Medications**	**Diet**	**Weight**
Age	1	2	5	4	1/5	0.189526
BMI	1/2	1	2	3	1/7	0.107074
Exercise	1/5	½	1	½	1/9	0.0445895
Psychotropic Medication	1/4	1/3	2	1	1/7	0.0609924
Diet	5	7	9	7	1	0.597818

λ_{max} = 5.22437, CI= 0.0560931, For n=5, CR= 0.050083 = 5.01% < 10% (acceptable)

Table 9
Paired comparison matrix level 2 with respect to factor 'OF'

	Organizational Environment	**Organizational Layout**	**Break Time**	**Scrutiny and Restrictions**	**Training/ Motivation**	**Weight**
Organizational Environment	1	2	1/3	4	0.2	0.136902
Organization Layout	0.5	1	1/7	2	0.333	0.0695371
Break Time	3	7	1	7	5	0.532869
Scrutiny and Restrictions	0.25	0.5	1/7	1	1/9	0.0396523
Training/ Motivation	2	3	0.2	9	1	0.221039

λ_{max} = 5.27915, CI= 0.0697881, For n=5, CR= 0.06231080 = 6.23% < 10% (acceptable**)**

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Table 10
Paired comparison matrix level 2 with respect to factor 'PF'

	Multiple Jobs	**House-hold Activities**	**Lack of Awareness**	**Nature / Behavior**	**Weight**
Multiple Jobs	1	2	7	4	0.523923
House-hold Activities	½	1	4	2	0.270708
Lack of Awareness	1/7	¼	1	½	0.0700147
Nature/Behavior	¼	½	2	1	0.135354

λ_{max} = 4.00223, CI= 0.000743219, For n=5, CR= 0.0008222222 = 0.08% < 10% (acceptable)

4. Discussion

The energy expenditure of workers was found to fall under the heavy workload category as recommended by the Indian Council of Medical Research (2010).The heart rate of workers also indicated that their job fell under the heavy workload category as it exceeded 120 beats/min which ultimately puts adverse stress on the human body (Maiti, R., 2008). The mean BMI of the majority of workers exceeded the normal range, and this consequently lowers the physical work capacity of these workers (Ismaila, S., Oriolowo, K., et al., 2012; Xu, X., Mirka, G. A. et al., 2008). The results from the Analytical Hierarchy Process showed the physical workload as the most significant factor as the workers lift and carry 50 kg loads for 7.5 meters. Ultimately, more energy expenditure would be needed to execute their task which directly causes whole body fatigue and muscle injuries (Pradhan, C. K., Thakur, S. et al., 2007; Waters, T. R., Putz-Anderson, V. et al., 1993). Diet has been pointed out as another factor as shown in Table 8. Improper and lack of sufficient diet intake increases chances of digestive problems, and also decreases retrieval rate of work-related injuries (Keusch, G. T., 2003; Montain, S. J., & Young, A. J., 2003). The present study also highlighted an insufficient break time of 45 minutes as an influencing factor which lowers recovery rate from exertion in the MMH job activity. This is because over exertion and insufficient rest pauses under heavy workload activities increase the chance of muscle injuries (Kee, D., & Seo, S. R., 2007). The salary of workers was found to be insufficient in light of their requirements therefore making it necessary for them to do multiple jobs which then leads to body fatigue due to restlessness. The current study explored various key factors which were still absent in the literature for developing countries like India, such as heavy workload, inadequate break time period, low income, lack of awareness about health issues, multiple jobs, household activities, nature/behavior and illiteracy rate among manual material handling workers in labor extensive occupations.

5. Conclusions

Manual material handling jobs are chosen by industrial management because of the lack of automation, which if applied, would involve considerable investment from the company. Workers can and are being engaged in manual material handling at cheaper wages due to unemployment and lack of awareness about health risks in these occupations. In the present study, the mean energy expenditure of workers revealed these MMH occupations as strenuous activity due to workload. Subsequently, the results of the AHP rated physical workload as the most influencing factor followed by physical work capacity, type of activity, organizational factors and personal factors. In conclusion, the study also explored the fact that the company is disregarding health and safety issues, as reflected in the insufficient diet intake, lack of rest pauses and inadequate salary for the workers which results in them seeking involvement in other occupations and increases the health risks.

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