ASSESSMENT OF ENERGY EXPENDITURE OF WORKERS BY USING 'AHP': A CASE STUDY OF PROCESS INDUSTRY

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ABSTRACT

The objective of research study is to develop an efficient multi-criteria approach for evaluation of various influencing factors that have a major impact on energy expenditure of workers engaged in manual lifting and carrying tasks. The present case study under taken sixty male workers having age between 30-60 years and performing manual lifting and carrying of 50kg fertilizer filled sac up to a distance of eight steps. Total Daily Energy Expenditure (TDEE) was found to be maximum among youngest age group i.e. in group I (30-40yrs) followed by group II (40-50yrs) and group III (50-60yrs). This study utilized a holistic method study to solve the problems in evaluating the various influencing factor that have a major impact on energy expenditure. The factors with the highest weights are determined by using analytical hierarchy process (AHP) which resulted physical workload as the most influencing factor (0.454139) followed by physical work capacity (0.252781), type of activity (0.129274), organisational factors (0.125318) and personal factors (0.038488) respectively. The results implicates that there is a need to redesign the work content of the occupation in order to reduce excessive energy expenditure of the workers.

Keywords: Manual material handling, Total daily energy expenditure (TDEE), Analytical hierarchy process (AHP), objective weight, preference index

1. Introduction

Manual material handling (MMH) tasks might expose workers to several risk factors, mainly of the physical sort. If performed repeatedly or over long periods of time, these tasks will lead to overwork and injury [1]. Manufacturing work is day by day wherever employees perform a variety of manual material handling tasks like to carry objects with varied weights and shapes from various locations [2] In many cases the human worker acts as a material transfer device in loading and unloading products from pallets, carts, machines or shelves to conveyors or overhead railings and/or playing advisement, performing or sorting on objects to and from moving conveyors and it leads to high rate of energy expenditure of body due to increase in physical workload. Overexertion, rapid work pace and repetitive motion patterns, intensive static effort or forceful exertions significantly contributed to the increase within the chance of musculoskeletal disorders [3]. There are numerous factors/parameters that have a major influence on energy expenditure and prioritization of these factors is being necessary to provide some control measures. Therefore, analytical hierarchy process has been used as a decision making technique so as to evaluate the affecting factors in terms of priority weights. Estimation of energy expenditure throughout work is very important for creating out a prescription for exercise moreover as up the physical workload [4]. World health organisation (WHO) has adopted factorial technique to estimate the energy necessities and it mostly rely on the weight, from which worker's metabolic process is predicted then to which energy expenditure throughout the activities of every day are connected as physical activity level value [5]. Physical workload represents the number of physical activity and movement within a selected timeframe [6].

Since, physical labor and manual material handling (MMH) will continue to be part in such industries that can't be eliminated and diverse studies have established that MMH is that the leading hazard in industry. The study develops a systematic approach using the analytic hierarchy method, a decision support methodology for multi-criteria analysis that allows the combination of tangible and intangible criteria for the evaluation of various influencing factors that have a major impact on energy expenditure to resolve a selected class of issues that involve prioritization of solutions by considering each qualitative and quantitative criteria.

2. Methods

The materials and methods used for the investigation are mentioned below the subsequent sub headings sub headings:

2.1. Selection of the workers

The study was conducted on sixty (60) male workers aged between 30-60 years performing manual lifting and carrying of 50 kg fertilizer stuffed sacs were selected by using convenience sampling from a process organization and divided in to three age groups viz. group I (30-40 years), group II (40-50 years) and group III (50-60 years).

2.2. Assortment of data/information

Data pertaining to age, education, physical activity, marital status, height, weight, and energy expenditure of the workers were recorded by a questionnaire. The questionnaire was pre tested and validated by using opinion of experts.

2.3. Energy Expenditure

Energy expenditure depends on the occupational activity, sleep and non-occupational activity, each typically for eight hours in a day. WHO has adopted factorial method to estimate the energy requirements, it largely depends upon the body weight, from which the worker's basal metabolism is predicted, and then to which energy spent during the activities of the day are related, as the physical activity level (PAL) value. The unit of energy expenditure is kilo calories (kcal) [5].

$$\textbf{TDEE} = \textbf{PREDICTED BMR} \times \textbf{PAL}$$

BMR is Basal metabolic rate is the amount of energy expended daily by humans at rest. Indian Council of Medical Research developed an equation to calculate the basal metabolic rate by considering the age.

Equation for prediction of BMR (kcal/24h): 10.9× Body Weight (kg) +833

PAL is Physical activity level is defined as the person's total daily energy expenditure in a 24- hour period, divided by Basal Metabolic Rate (BMR). The physical activity level is then the time-weighted average of the physical activity ratios.

$$\textbf{PAL} = \frac{\textbf{TDEE/24h}}{\textbf{BMR}}$$

2.4. Analytical hierarchy process

The AHP has been used in almost all applications related to decision-making and this method allows the incorporation of tangible and intangible factors that would otherwise be difficult to take into account [7]. The importance or preference of the decision criteria are compared in a pair-wise comparison manner with regard to the criterion preceding them in the hierarchy [8]. The AHP has been applied for many purposes (e.g. selection, evaluation, allocation, etc.) and in different areas of applications (e.g. personal, social, manufacturing, engineering, education, sports, etc.). AHP allows a better, easier, and more efficient identification of selection criteria, their weighting and analysis. The process makes it possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria [9]. Additionally, subjective preferences, expert knowledge and objective information can all be included in the same decision analysis [10] particularly if the process involves group decision making. Briefly, and according to [11], the step-by-step procedure in using AHP is the following:

Step 1: Build the hierarchy: AHP hierarchy is a structured means of modeling the decision and depends on the nature of the problem, knowledge, judgments, values, opinions, needs, etc. of the participants in the decision-making process. A group of experts from different organizations participate in the decision-making group to identify evaluation criteria, and to establish evaluation criteria hierarchy. Three-level hierarchy model has been used to evaluate the energy expenditure. It may be seen that level 1 refers to the overall objective, level 2 is composed of five main criteria named as Physical workload (PW), type of activity (TOA), physical work capacity (PWC), organisational factors (OF) and personal factors (PF) and level 3 is made up of 23 sub-criteria. Links are drawn to form the hierarchy and the relationship among objective as shown in Figure 1.

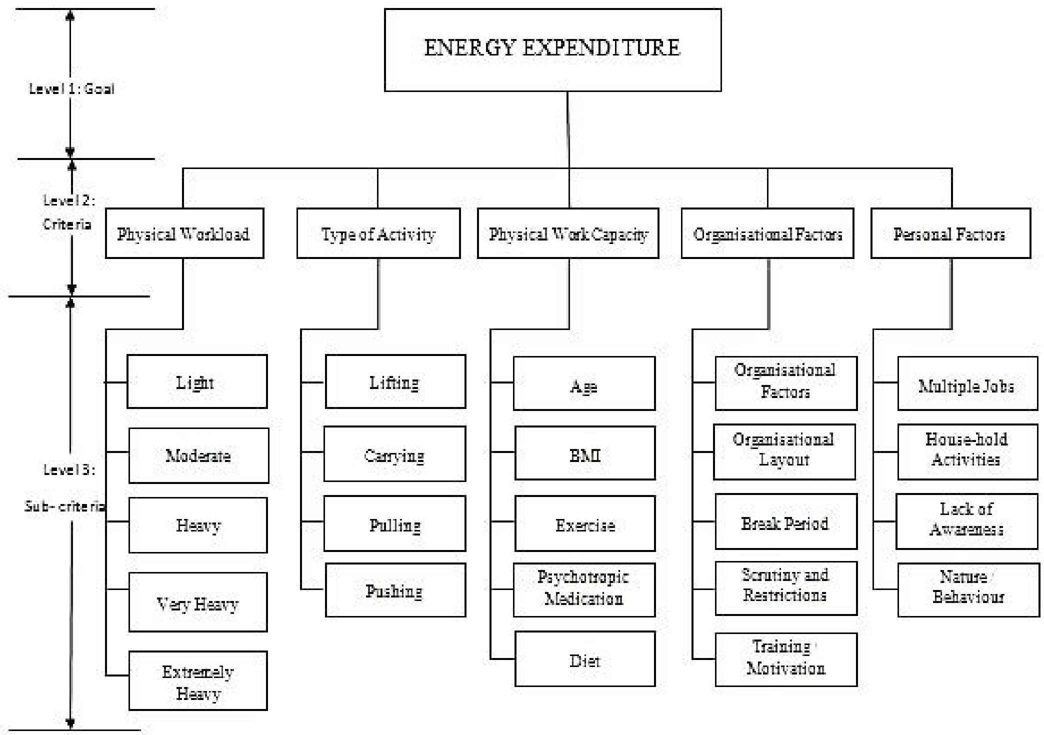

Figure1. AHP decision- making hierarchy

Step 2: Degree of preference: The degree of preference or intensity of the decision maker in the choice of each pair-wise comparison used in this model is quantified on a scale of 1-9. This scaling process has been translated into priority weight for comparison of sub-objectives. Even number (2, 4, 6, 8) can be used to represent compromises among the preference above. The suggest numbers used in this model to express degree of preference are shown in Table 2.

Table 2: Degree of preference

Value	Judgement	Description
1	Equal	Two alternatives share the same level of importance
3	Moderate	Experience and judgement favours one alternative with respect to the other in little measure
5	Strong	Experience and judgement strongly favour one attribute over another

7	Very strong	Experience and judgement 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

Step 3: Pair-wise comparison of different sub-objectives. The importance of ith sub-objective has been compared with jth sub-objective. In the present stud, 23 sub- objectives have been taken as shown in Figure 1.

Step 4: Normalized matrix of different sub-objectives: After a pair-wise comparison matrix is obtained, the next step is to divide each entry in column by the sum of entries in column to get value of normalized matrix. The values of normalized matrix rij are calculated as given in the formulae mentioned below:

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

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

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

Step 5: Do consistency checks: The consistency index (CI), which measures the inconsistencies of pair-wise comparisons is calculated as:

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

The formulation of CR is:

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

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: λmax is the maximum eigen value, n is dimensional matrix.
Generally, if CR is less than 0.1, the judgments are consistent and acceptable, so the derived weights can be used [11].Where, random consistency index (RI) as shown in Table 3and it is fixed for every dimensional matrix.

3. Results

As per qualitative data following results have been drawn:

3.1 Physical parameters of the workers

Table 4 showed that height of the workers in group I was maximum (168.77cm) followed by group III and II i.e.165.25 and 160.34 cm, respectively (fig. 3). There was not much variation in the weight of workers. Weight of the workers was 70.8, 69.7 and 70.25 kg in group I, II and III respectively. The result of present study revealed that range of body mass index was 24.6 to 28 kg/m2. The mean average value of body mass index of the workers was 25.92±1.50, 26.33±2.28 and 26.42±2.16 kg/m2 in group I, II and III respectively. Total Daily Energy Expenditure was found to be maximum among youngest age group i.e. in group I (3557.3kcal) followed by group II (3311.3kcal) and group III (3240.7kcal) which was very high as compared to recommended value (2873kcal).

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
TDEE (kcal)	3557.3 ±318.50	3311.30 ±257.06	3240.74 ±279.03

3.2 Analytical Hierarchy Process

All of the pair-wise comparisons performed to work out the priorities of all elements were applied by the evaluation team using the 9-point scale urged by [11]. As per the initial step of the AHP procedure, the activity entailed the formulation of a schematic hierarchy supported the AHP model containing a goal and a pair of levels of elements (criteria and sub-criteria). There are five criteria that have major impact on energy expenditure, named as physical workload (PWL), type of activity (TOA), physical work capacity (PWC), organizational factors (OF) and personal factors (PF).

Table 8: Paired comparison matrix level 1 with respect to objective

	PWL	TOA	PWC	OF	PF	Weight
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 9: 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 10: 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 11: Paired comparison matrix level 2 with respect to factor PWC

	Age	BMI	Exercise	Psychotropic Medication	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 12: Paired comparison matrix level 2 with respect to factor ‘OF’

	Organisational Environment	Organisational Layout	Break Time	RestrictionsScrutiny and	MotivationTraining/	Weight
Organisational Environment	1	2	1/3	4	0.2	0.136902
Organisation 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**)**

Table 13: Paired comparison matrix level 2 with respect to factor ‘PF’

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

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

As per result obtained by AHP as shown in Table 8, the physical workload found to be most influencing factor (0.454139) followed by physical work capacity (0.252781), type of activity (0.129274), organizational factors (0.125318) and personal factors (0.038488). The result obtained from pair-wise comparison matrix showed ‘heavy’ because the most consideration sub-criteria with regard to factor PWL as shown in Table 9. Within the same approach ‘carrying’ has been resulted as most weighing sub-criteria with relevancy to factor TOA as shown in Table 10. Similarly, Table 11 accomplished

'Diet' as the most impacting sub-criteria in pair-wise comparison matrix with respect to factor PWC. On the opposite hand, it was absolutely noted just in case of Table 12&13 that 'Break time' and 'Multiple jobs' has been evaluated as most consideration sub-criteria with respect to factor OF&PF respectively.

4. Conclusion

As per result obtained by AHP it has been concluded that the physical workload found to be most influencing factor (0.454139) followed by physical work capacity (0.252781), type of activity (0.129274), organizational factors (0.125318) and personal factor (0.038488). The result obtained from pair-wise comparison matrix showed 'heavy' because the most consideration sub-criteria with regard to factor PWL. Within the same approach 'carrying' has been resulted as most weighing sub-criteria with relevancy to factor TOA. Similarly, 'Diet' has been found to be the most impacting sub-criteria in pair-wise comparison matrix with respect to factor PWC. On the opposite hand, it was absolutely noted that 'Break time' and 'Multiple jobs' has been evaluated as most consideration sub-criteria with respect to factor OF&PF respectively. However, the case study establishes the role of AHP as a systematic methodology in identifying and weighing criteria, analyzing gathered information, and expediting the process of decision-making.

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