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Ergonomics Evaluation for the Operation Performed on Lathe Machine using Energy Expenditure Prediction Program

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Abstract - *Analyzing and presenting a basic understanding of ergonomic evaluation using the Energy Expenditure Prediction Program (EEPP) software designed by University of Michigan in order to bring about maximum efficiency, productivity and safety of a worker in a production environment. The energy expenditure was carried out for activities in the machining operations on a lathe machine, this study has gauged the workers fatigue with greater accuracy and feasibility than laboratory techniques.*

Keywords: Energy expenditure, Productivity, Ergonomics, Lathe machine, Environment

1. INTRODUCTION

Manufacturing tasks are classified as jobs that involve creation of new products from the materials provided. Different machines and techniques are explored and unified under a roof in order to produce a flawless final product, these products are made by skilled workers performing different sets of operations and tasks such as turning, drilling, machining, welding, etcetera in order to produce the final consummate product required or ordered by the consumer/customer. The numerous tasks that are practiced and perfected in order to produce the final product require facilitation and involvement of workers and their skills. Apart from production environment Ergonomist, applied physiologist, sports scientist, nutritionist and epidemiologist required the estimates of activity patterns and energy expenditures. Metabolic expenditure rate is the physiological measurement which has been suggested to determine the maximum task intensity that can be performed continuously without fatigue

Ergonomist, applied physiologist, sports scientist, nutritionist and epidemiologist requires the estimates of activity patterns and energy expenditure. Methods generally employed for the measurement of energy expenditure are:

- 'Gold Standards' method
- Accelerometer
- Portable metabolic unit
- Pedometer
- Doubly labeled water
- Polar heart rate monitor
- Motion sensors
- Thermal imaging, etc.

Recent technological advancements in the sensor technology along with great progress made in algorithms have made the energy expenditure prediction a very powerful technique used to asses everyday physical activity. The prediction of energy consists of following components,

- Maintenance expenditure
- Diet-induced energy expenditure
- Activity-induced energy expenditure

A model of muscle energy expenditure was developed for predicting thermal as well as mechanical energy liberation during simulated muscle contractions (Umberger et al. [1])

Most of the work and tasks done during a manufacturing process is completed by hand on machines by workers. The procedures involved in these processes are rough and dangerous if precautions and safety measures are not followed as per the guidelines. As a result, the metabolic energy expenditure rate is calculated, this rate is a physiological measurement which has been put forward by the NIOSH in order to calculate the maximum task intensity that a worker can perform ceaselessly without amassing an exuberant amount of physical and mental fatigue. (Table 1)

Table -1: Human – Lathe Machine, Task work/Activity

TASK	TASK WORK	ACTIVITY
1	Cleaning	Arm Work - General-Light-Both Arms
2	Obtaining semi-finished product	Walk – on flat or inclined surface
3	Fixing the Job on Lathe Machine	Lift- Squat

4	Lifting the semi-finished product	Push/Pull - Regular load
5	Performing operation on Hand wheel	Handwork - General-Light-Both Arms

Skeletal muscles may be thought of us biochemical machines with chemical energy stored in adenosine triphosphate (ATP) going into the muscle and being converted to mechanical work and heat energy Sherwood [2] and Umber et al. [1].

Metabolic energy expenditure rate is the physiological measurement which has been suggested in the literature to determine the maximum task intensity that can be continuously performed without accumulating an excessive amount of physical fatigue [3]. Energy expenditure limits are often defined as a rate of oxygen consumption per min (VO2) in the domain of human factors and ergonomics and a limit of 1 liter of oxygen per min (approximately 5 kcal per min) is considered as a design criterion [4]. There are three approaches to measure energy expenditure [5]: i) oxygen consumption and/or carbon dioxide production is measured by using indirect calorimetry and converted to energy expenditure using formulae. ii) The rate of heat loss from the subject to the calorimeter is measured by using the direct calorimetry. iii) A number of non-calorimetric techniques have been applied to estimate the energy expenditure by extrapolation from physiological measurements and observations. There are several devices that can accommodate minute-by-minute information based on physical activity patterns. However, their validity to perform energy expenditure is not sufficient. For instance, several devices have performed better in a laboratory setting than nonlaboratory conditions.

Przybyszewski [6] predicted energy expenditure from physical activity PA, heart rate HR and anthropometry in female tea pluckers, An EE prediction equation was generated using a branched method that first distinguishes time during normal workday activities (walking, resting and plucking) using accelerometer counts. Resting EE was estimated from age, weight, while minute-by-minute non-resting EE was estimated from HR and Body Mass Index (BMI).

Levine [5] reviewed and assessed metabolic needs, fuel utilization and the relative thermic effect of food, drink, drugs and emotional components for measurement of energy expenditure in humans. He suggested where high accuracy is required and sufficient resources are limited and/or optimum precision can be sacrificed, flexible total collection systems and non-calorimetric methods are potentially useful if the limitations of these methods are appreciated.

Non-calorimetric methods Ocobock [7] for estimating energy expenditure are often used due to their ease of use and relative economy. These methods estimate energy through physiological variables that are related to energy expenditure such as heart rate, muscle activity. These methods have been standardized and validated using calorimetric methods.

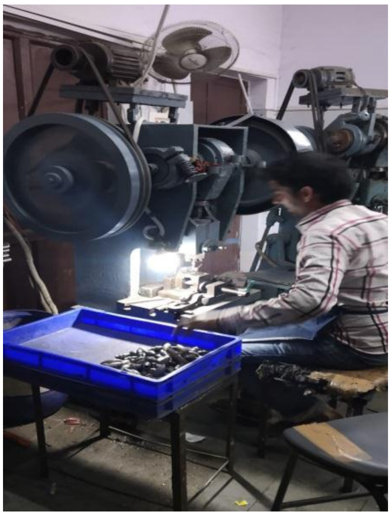
Levine [5]. Five different methods were also used like integrated electromyography, pulmonary ventilation volume, thermal imaging, flex heart rate and doubly labeled water method.

Zakeri et al. [8] have constructed Multivariate adaptive regression splines (MARS) models based on heart rate (HR) and accelerometer counts (AC) to accurately predict EE, and hence 24-h total energy expenditure in children and adolescents. Hay et al. [9] applied an artificial neural network technique to the problem of predicting energy expenditure with several dynamic input values including accelerometry, heart rate above resting (HR), and electromyography (EMG). There are various software tools in literature to predict energy expenditure. The University of Michigan's Energy Expenditure Prediction Program (EEPP) is one of them which predict metabolic energy expenditure rates by integrating the energy requirements of small, well-defined work tasks that comprise the entire job [10]

2. METHODOLOGY

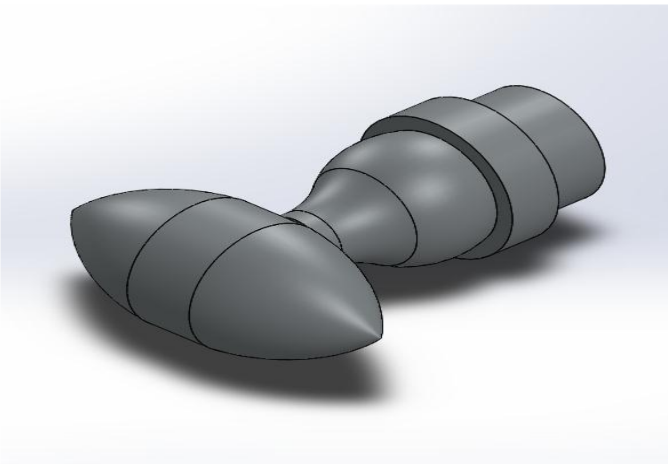
This study aims to point out an approach to estimate energy expenditure rates for waste collection task using The University of Michigan EEPP. This software basically, estimates the energy rate of the job by knowing the energy requirements of simple tasks that comprise the entire job. For this reason, task has been divided in 5 individual tasks is represented in Table 1

Fig - 1: Experimental Setup

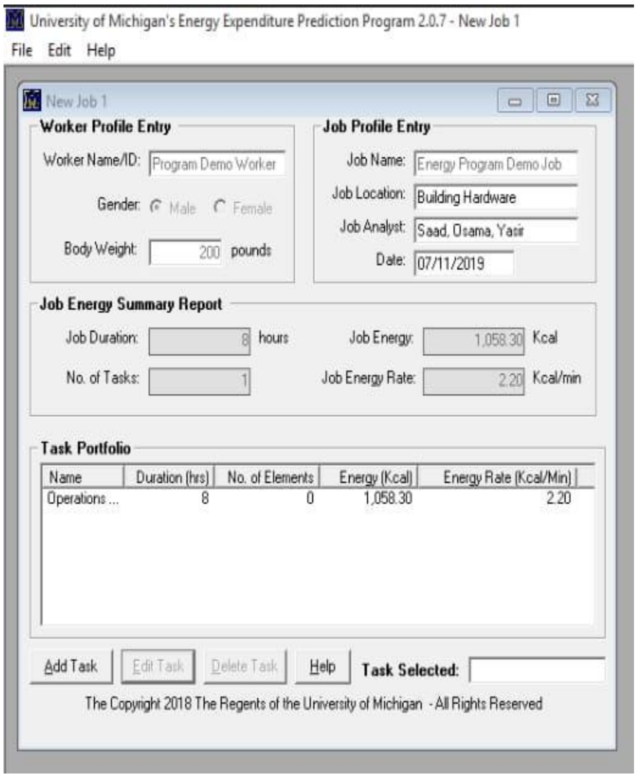


The information for each task required to calculate the energy requirements including force exerted, distance moved, frequency, task posture, lifting technique for lifting tasks, and time required to compute the tasks. Furthermore, gender and body weight are also needed. This information is separated as program inputs and outputs: inputs are subject's gender and weight, list of activity elements, and parameters specific to activity elements (e.g. frequency, weight of load, distance carried); outputs are: listing of activity elements with their corresponding energy expenditure, calculation of the total energy expenditure rate for the job in Kcal/minute. The experiment was performed in Manufacturing Lab, Gul Industries, Aligarh, India. Based on these surveys, total task time, frequency, distance moved (walk to the container and walk back to the container) were entered into the software and predicted energy results were summarized. Finally, the results from the analysis section were compared with regression models in literature and the NIOSH guidelines, then interpreted in a wider context regarding their effect and meaning in terms of the ergonomic assessment.

Fig - 2: Work part (3D) used for Energy Expenditure measurements



The following screenshot illustrates EEPP after the data has been entered.



A glance at the summary energy expenditure rate of 11.95 kcal/min at the bottom of the screenshot above alerts the safety engineer that the job is too fatiguing. It significantly exceeds the kcal/min action limit guideline for an average 8-hour day set by the National Institute for Occupational Safety and Health (NIOSH). Data from the job changes are entered into the program resulting in the following screenshots:

Fig – 3: Task 1; Cleaning

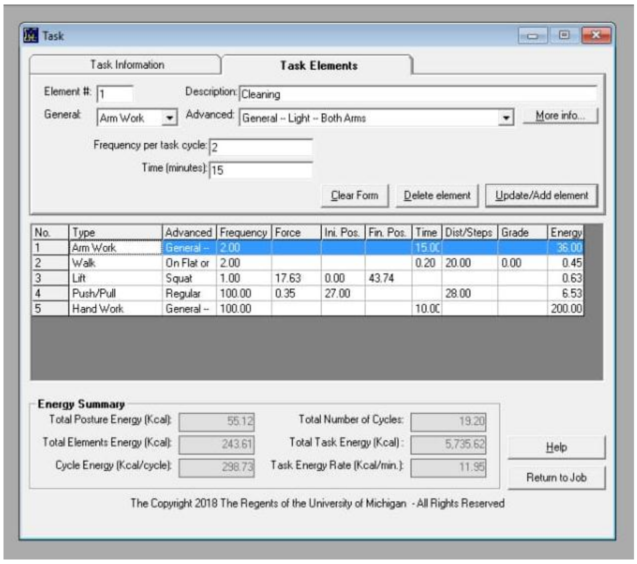


Fig – 4: Task 2; Obtaining semi-finished product

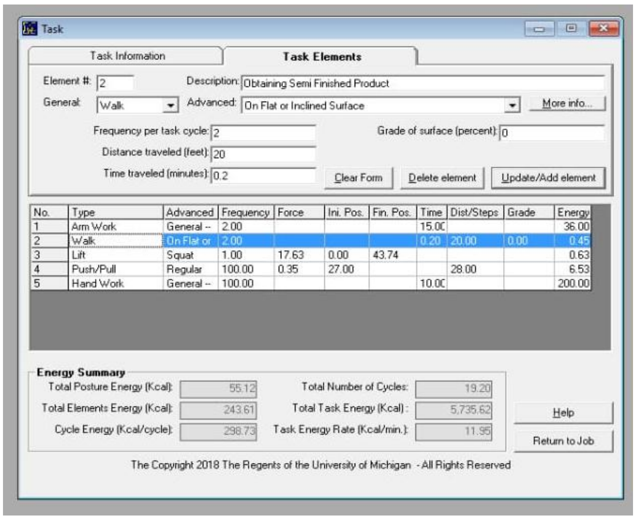


Fig – 5: Task 3; Lifting the semi-finished product

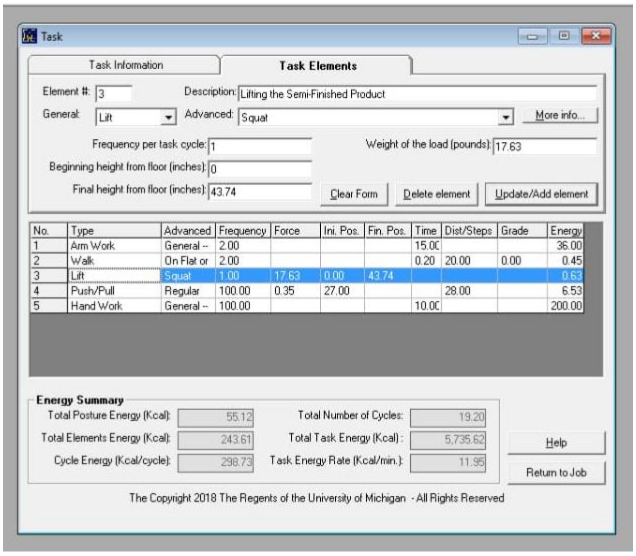


Fig – 6: Task 4; Fixing the job on the lathe machine

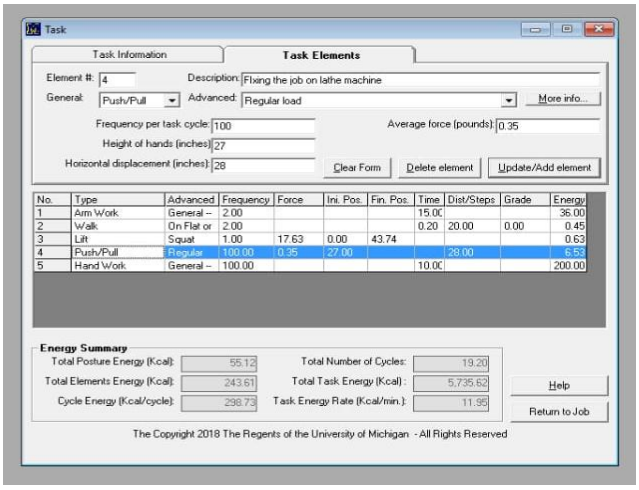
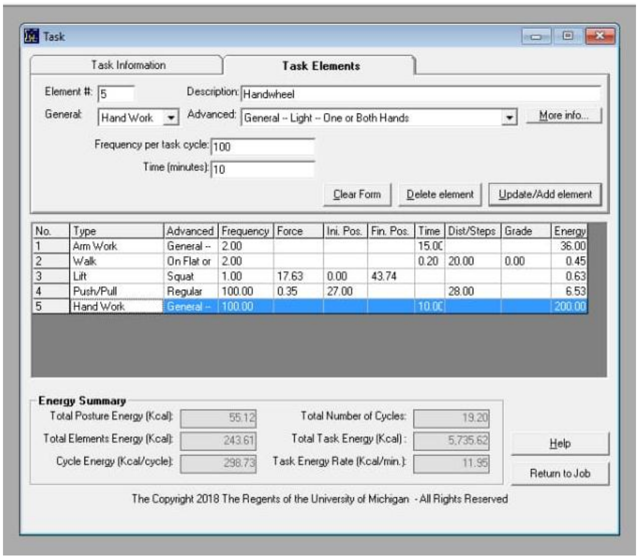


Fig – 7: Task 5; Hand wheel Operation



3. RESULTS and DISCUSSION

3.1 Assumptions

There are some assumptions needed to do before data analysis. Since data was gathered from surveys, it was not possible to extract some of these variables. These approximate values are follows: Distance travelled for walking task is assumed 20 Steps Average forces applied for pushing and pulling tasks are assumed 17.63 pounds and 0.35 pound respectively, and height of hands and horizontal displacement are assumed 27 and 28 inches respectively.

3.2 Prediction Model

Equations 2 to 5 for the net metabolic cost (ΔE) of each task as a function of personal and task variables were performed using least squared error regression analysis [11]. Some of these equations are considered for our model, these equations are:

(i)Maintenance of body posture: (1) Standing $\dot{E} = 0.024*BW$

(ii) "Net metabolic cost of tasks:" (2) "Stoop lift (Kcal/lift)"

"$\Delta E = 10\text{-}2 *[0.325*BW*(0.81-h1) + (1.41*L+0.76*S*L) (h2-h1)$ for $h1<h2\leq 0.81$"

(3) Walking (Kcal) $\Delta E = 10\text{-}2 *(51+2.54*BW*V2 +0.379*BW*G*V) *t$

(4) "Holding at arm's length, against thighs or at sides (both hands) (Kcal)" $\Delta E = 0.037*L*t$

(5) "Pushing/pulling, at bench height (0.8 meter) (Kcal/push)"

$\Delta E = 102 * X*(0.112*BW +1.15*F+0.505*S*F)$

Where: $\dot{E}$ = Metabolic rate (Kcal /min.) ΔE = "Kcal for walking, carrying and holding. For all other tasks, units are Kcal/performance." BW = "Body weight(kg)" F = "Average pushing/pulling force applied by hands (kg)" G = "Grade of the walking surface (%)" h1 = "Vertical height from floor (m); starting point for lift and end point for lower." h2 = "Vertical height from floor (m); starting point for lift and starting point for lower."

L =" Weight of the load (kg)"

S =" Gender; 1 for males; 0 for females"

V =" Speed of walking(m/s)"

X =" Horizontal movement of work piece(m)"

t =" Time (minutes)"

After using required data for each equation, Epos. (From equation 1) and ΔE have been calculated.

$$\boxed{\bar{\dot{E}}\ \mathbf{job} = \left(\sum_{i=1}^{ni} \dot{E}\ pos * ti + \sum_{i=1}^{n} \Delta E\ task\ i\right)/T}$$

$\bar{\dot{E}}$ job = "Average energy expenditure rate of the job (kcal/min)"

$\dot{E}$pos = "Metabolic energy expenditure rate due to maintenance of ith posture (kcal/min)"

Ti = "Time duration of ith posture (min)"

Ni = "Total number of body postures employed in the job"

ΔE task i = "Net metabolic energy expenditure in the ith task in steady state (kcal)"

N = "Total number of task in the given job"

T = "Time duration of the job"

4. CONCLUSIONS

This study shows that the energy expenditure can be predicted for waste collection task by using software and prediction models. The results show that the difference between software output and prediction equation result is small and can be ignored. This predicted information can be useful for waste collection job design instead of using oxygen consumption measurement which takes long time and costly. Furthermore, these prediction approaches can be used for other practical applications. In this study, the demo version of the software has been used, that is why there are some limitations in entering gender and body weight to the software. Gender and body weight are set as male and 200 pounds respectively. Since all participants are male, only body weight might have had an effect on the results. Other assumptions based on limitations are also explained in result section. For future studies, these limitations and restriction should be considered and this study can be extended by using other software in literature to compare with each other, to get common result and to see advantages and disadvantages of individual software.

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BIOGRAPHIES

Areas like Machine design, Operation Research, Fluid Mechanics interest me, but I am always looking for opportunities to diversify my professional experience and expand my practical knowledge through such mediums and both grow myself professionally and contribute to the success of others.

I intend to use my experience working in a team-oriented environment and managing time-sensitive tasks to help achieve the goal that has been set. My particular areas of interest are Manufacturing Technology, Ergonomics, Production Engineering & Material Science.

I believe that hard work with a little touch of finesse is the key to success in areas like fluid machinery, energy conservation, manufacturing technology, areas that I find myself very interested in. I am eager to learn new skills and techniques that will help me and my team grow and move forward towards perfection