Multi-Response Optimization of Manual Material Handling Tasks through Utility Concept

Jaswinder Singh, P. Kalra and R.S. Walia

Abstract--- *In this work six Manual Material Handling (MMH) task parameters such as box size, Body Mass Index (BMI), frequency of lift, load lifted, vertical distance of lift, and asymmetric angle were chosen for multi response optimization of task parameters. Most of the existing approaches for multi response optimization of process parameters focus upon the subjective and practical knowledge available about the process. This is particularly true in case of Taguchi based optimization. however, this approach introduces some uncertainties and confusions in overall decision-making process. keeping in view these limitations, an approach based on a utility theory and Taguchi quality loss function (TQLF) has been applied to MMH tasks for simultaneous optimization of more than one response characteristics.*

Keywords--- *MMH Tasks, Multi Response Optimization, Taguchi Approach, Utility Concept, Heart Rate and Oxygen Consumption*

I. INTRODUCTION

MANUAL Material Handling (MMH) includes a wide variety of activities such as loading and unloading boxes, removing materials from a conveyor belt, stacking items in a warehouse, etc. As a result, workers may suffer from musculoskeletal disorders (MSDs). Various short and long term health effects are attributed due to MMH tasks. MMH tasks are very common in workplaces. MMH tasks are the main cause of severe injuries all over the world. More than a quarter of all injuries related to industrial work are directly associated with MMH activities. The cost associated with these injuries is very high. In order to control these occupational injuries various research and design guidelines have been proposed [1-3]. There are many physiological parameters (Heart rate, Oxygen consumption, Blood pressure etc.) which affect the MMH tasks. To reduce the occupational injuries due to MMH tasks performed at high frequencies, the MMH task parameters should be selected carefully and then optimized. In the MMH task scenario, it is most vital to optimize the physiological parameters of task to exploit its full utility. Practically, it is seen that one particular setting of input parameters for a response characteristics may not be suitable for other characteristics of MMH tasks. In most of the MMH tasks, more than one quality characteristics has to be considered for optimization of process parameters making it necessary that several response characteristics have to be simultaneously optimized. Therefore, in the situations involving many measurable response characteristics of a product/ process, an optimization strategy is required that can provide a unified criterion to represent the overall optimal setting of process parameters with respect to all the responses. These types of optimization problems need to be handled by multi-response optimization techniques. In the past, the applications of Taguchi method and Response Surface Methodology (RSM) have mainly dealt with single response problems [4-7] and only very few applications are reported for multi-response problems [8-9]. Shiau solved the Multi-response problem by assigning the weights to S/N ratio of each quality characteristic and than summing up the weighted S/N ratios for the measurement of overall performance of a process [10]. Tai et. al. used empirical loss functions for evaluating multi response problem by involving six parameters and nine responses for the surface mount process [11]. Singh studied the optimization of the quality characteristics of Magnetically Assisted Abrasive Flow Machining (MAAFM) process by using multi-response optimization through utility concept and Taguchi method [12]. Walia *et al.* studied Multi-response optimization of centrifugal Force Assisted Abrasive Flow Machining (CFAAFM) process through Taguchi method and Utility Concept [13]. Goyal *et al*. studied optimization of Low- pressure cold sprayed coatings process parameter using Taguchi multi-response [14]. Singh *et al.* studied the parametric optimization of Hybrid Electric Discharge Machining process with continuous and discontinuous ultrasonic vibrations on work piece [15]. Based on the foregoing discussions, in this paper, Taguchi method is briefly reviewed for the multi-response optimization. The multi-response optimization of the response parameters of MMH tasks is then presented by using the experimental data. Optimization models have been developed by combination of the Taguchi Method and the Utility concept. Two response parameters i.e., Heart rate, Oxygen consumption has been taken in this study for Multi response optimization.

II. WORKERS DETAILS

Body Mass Index (BMI) is used to indicate if an individual is underweight, normal or overweight. WHO (2003) categorized persons in three types namely underweight, normal weight and overweight based on their BMI [16]. A normal weight person BMI score is between 18.5 and 25 kg/m^2. A score below 18.5 indicates that a person is

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underweight; a value above 25 indicates that a person is overweight. Eighteen male workers with different BMI and having 10 years of experience were selected for this laboratory study. An anthropometric kit was used to measure anthropometrical data. Height of workers was measured without shoes using an anthropometer. Body weight was measured without shoes using a portable digital scale. The BMI was calculated by dividing body mass of a person in kilogram to square of his height in meter. The anthropometric details of the workers in shown in Table 1.

Table 1: Anthropometric details of the Workers

Parameter of workers	Underweight workers BMI (kg/m^2)< 18 (Total number of workers=6)		Normal weight workers BMI (kg/m^2)=18-24.9 (Total number of workers=6)		Over weight workers BMI (kg/m^2)>24.9 (Total number of workers=6)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	26.7	4.23	27.17	2.86	26.5	3.94
Weight (kg)	45.5	5	55.7	4.81	67.27	3.28
Stature height (cm)	165.13	9.26	162.22	6.49	158.47	3.34
BMI (Kg/m^2)	16.66	0.48	21.23	2.30	26.84	0.86

III. MEASURING EQUIPMENT DETAILS

Cosmed Fitmate Pro equipment was used to measure the Heart rate and the Oxygen consumption responses. The equipment gives two response curves one for Oxygen consumption and another for Heart rate simultaneously on same time frame. For getting the Oxygen consumption readings a face mask was attached to the face of worker. A head cap with connectors was used for properly securing of the mask to a fixed position on worker's face during experiments. The measurement is made through a wired turbine one end of which is connected to the mask and other end connected to the equipment. For getting Heart rate readings a Polar belt was put around the chest of the worker. For transferring Heart rate signals to equipment a probe was attached near the polar belt with the help of clamp provided on the probe and other end of probe was attached to equipment through a wire. Time of experiment was noted with a stop watch.

IV. MULTI-RESPONSE OPTIMIZATION THROUGH UTILITY CONCEPT AND TAGUCHI METHOD OF MMH TASK PARAMETERS

The experiments were designed using Taguchi fractional factorial technique to study the effect of six factors: box size, BMI, frequency of lift, load lifted, vertical distance of lift, and asymmetric angle on response parameters such as oxygen uptake and Heart rate of workers. Taguchi L18 orthogonal array (OA) has been adopted for conducting the experiments [17-18]. Factors like horizontal distance, origin of lifting, room temperature were kept constant during the experimental study. The ranges of the selected MMH task parameters were based on the pilot study in laboratory and observation of the manual lifting tasks in industries. For representing each BMI level six workers per BMI level were taken, so total of eighteen workers participated in this work.

Table 2: MMH task Parameters at Different Levels

S. No	Symbol	Factors	Levels			Units
			Level-1	Level-2	Level-3	
1	A	Box size	Small	Large	-------	cm^3
2	B	BMI	Under weight	Normal weight	Over weight	Kg/m^2
3	C	Frequency of lift	2	4	6	lifts/min
4	D	Load lifted	15	19	23	kg
5	E	Vertical distance	Knee	Waist	Shoulder	cm
6	F	Asymmetric angle	0	30	60	deg
Horizontal distance: 25cm, Environment conditions : 32 ± 2^0C						

Lifting frequency was set at three levels of 2,4 and 6 lifts/min. Workers were lifting the weight from 14 to 20 kg in industries. Therefore weight is taken at three levels 15, 19 and 23kg. 23 Kg of higher load limit is set because it is the maximum load allowed to be lifted by NIOSH 1991. Vertical distance was varied at three levels which were set at knee, waist and shoulder respectively of the workers. Two wooden boxes of small and large size were used for the experiments. The dimension of small box is 60x40x17.5 cm^3 and that of large box is 60x40x27.5 cm^3. These box sizes are used in the industries for manual lifting tasks. Asymmetric angle was varied at three levels mainly 0, 30 and 60 degree respectively. Horizontal distance was fixed at 25cm for all experiments. All the experiments were performed at room temperature of 32 ± 2^0C. In this research work Taguchi's mixed level design was selected as it was decided to keep two levels of box size. The remaining five factors were studied at three levels. The selected number of factors and their levels are given in Table 2. Two level factor has 1 DOF and each of three level factors have 2 DOF, i.e., the total DOF required will be 11(=1×1+5×2).The most appropriate orthogonal array in this case is Taguchi L18 OA with (18-1) DOF. The unassigned columns were treated as error. Excel sheet was used for analyzing the results. To reduce error for each trial, experiments were repeated three times. All the experiments were conducted on experimental setup design and developed in Human Engineering laboratory of PEC University of Technology, Chandigarh, India. Experimental setup was made in such a way that it could be adjusted to various heights. To determine which factors significantly affect the response characteristics, main effect for raw data and S/N data had been calculated. In addition, plots of the various factors were developed to show significance. For the both Oxygen consumption and Heart rate lower the better response characteristic were taken for calculation of S/N data.

A mixture of sand and pebbles were used as the load material for the experiments. Free style lifting technique was used during experiments. Lifting of the boxes was done as per the experiment array by the worker on the experimental setup while lowering of the boxes was done by volunteers. In each of the trial conditions and for every replication, Heart rate and the oxygen uptake were measured. The effect of selected MMH task parameters was studied on the following response characteristics:

- Heart rate (HR)
- Oxygen consumption (VO_2)

Heart rate and Oxygen consumption are “smaller the better” type of quality characteristic. A simplified multi-criterion methodology based on Taguchi’s approach and utility concept (given below) is used to achieve the objective of this study. A product or a process is normally evaluated on the basis of certain number of quality characteristics, sometimes conflicting in nature. Therefore, a combined measure is necessary to gauge its overall performance, which must take into account the relative contribution of all the quality characteristics. In the following, a methodology based upon Utility concept and Taguchi method is developed for determining the optimal settings of process or parameters for multi-response/ multi-characteristics process or product. The multi-response optimization of quality characteristic of MMH tasks has been carried out by using this methodology given in this section.

A. Utility Concept

Utility can be defined as the usefulness of a product or a process in reference to the expectations of the users. The overall usefulness of a process/product can be represented by a unified index termed as Utility which is the sum of the individual utilities of various quality characteristics of the process/product. The methodological basis for Utility approach is to transform the estimated response of each quality characteristic into a common index.

If Xi is the measure of effectiveness of an attribute (or quality characteristic) i and there are n attributes evaluating the outcome space, than the joint Utility function can be expressed as [19]:

$$U(X_1, X_2, \ldots X_n) = f(U_1(X_1), U_2(X_2) \ldots . U_n(X_n)) \quad (1)$$

where Ui(Xi) is the utility of the ith attribute.

The overall Utility function is the sum of individual utilities if the attributes are independent, and is given as follows:

$$U(X_1, X_2, \ldots X_n) = \sum_{i=1}^{n} U_i(X_i) \quad (2)$$

The attributes may be assigned weights depending upon the relative importance or priorities of the characteristics. The overall utility function after assigning weights to the attributes can be expressed as:

$$U(X_1, X_2, \ldots X_n) = \sum_{i=1}^{n} W_i U_i(X_i) \quad (3)$$

where Wi is the weight assigned to the attribute i. The sum of the weights for all the attributes must be equal to 1.

B. Determination of Utility Value

A preference scale for each quality characteristic is constructed for determining its utility value. Two arbitrary numerical values (preference number) 0 and 9 are assigned to the just acceptable and the best value of the quality characteristic respectively. The preference number (Pi) can be expressed on a logarithmic scale as follow [20-21]:

$$P_i = A \times \log\left(\frac{X_i}{X_i^{'}}\right) \quad (4)$$

Where, Xi = value of any quality characteristic or attribute i

$X_i^{'}$ = just acceptable value of quality characteristic or attribute i

A = constant

The value of A can be found by the condition that if Xi = X* (where X* is the optimal or best value), then Pi = 9

Therefore,

$$A = \frac{9}{\log \frac{X^*}{X_i^{'}}}$$

The overall utility can be calculated as follows:

$$U = \sum_{i=1}^{n} W_i P_i \quad (5)$$

Subject to the condition: $\sum_{i=1}^{n} W_i = 1$

Among various quality characteristics type viz. smaller the better, higher the better, and nominal the better suggested by Taguchi, the Utility function would be higher the better type. Therefore, if the Utility function is maximized, the quality characteristics considered for its evaluation will automatically be optimized (maximized or minimized as the case may be). The stepwise procedure for carrying out multi-response optimization with Utility concept and Taguchi method is illustrated in a Table 3.

Table 3: Methodology for Multi-Response Optimization by Utility Concept and Taguchi method

Step 1	Using Taguchi Parametric design approach, determined the optimal values and setting of each of response characteristic of VO_2 and HR, for the manual lifting task responses.
Step 2	Constructed a preference scale for each response characteristic, based on their optimal values and minimum acceptable level (Equation 5.4).
Step 3	Assigned weights (W_i) to the selected quality characteristics based upon the importance, experience or any other constraint, keeping in view that the total sum of weights is equal to 1.
Step 4	Determined the overall utility values corresponding to each experimental trial conditions (based on L_{18} OA for present investigation, Equation 5).
Step 5	Used these values and the calculated S/N ratio as responses for the trial conditions of the selected L_{18} OA. S/N ratio of higher-the-better type is selected as the utility is a higher-the-better type characteristic [17].
Step 6	Analyse the results using the Taguchi Method.
Step 7	Find the optimal settings of manual lifting task parameters for optimal utility based on the analysis performed in step 6.
Step 8	Predicted the values of different response characteristics based upon the optimal significant parameters determined by the previous step.
Step 9	Performed the confirmation experiments at the

	optimal settings to verify the optimal results.

V. MULTI-RESPONSE OPTIMIZATION FOR MMH TASK RESPONSE PARAMETERS

To obtain the optimal settings of the process parameters of MMH tasks for predicting the optimal values of combined responses, both the quality characteristics (HR and VO_2) have been included in utility response.

A. Heart Rate (HR) and Oxygen Consumption (VO2)

Taguchi L18 orthogonal array (OA) has been adopted for conducting the experiments [17-18]. Box size (A), BMI (B), Frequency of lift (C), Load lifted (D), Vertical distance (E) and Asymmetric angle (F) were selected as input parameters. Response parameters (quality characteristics*)* were Heart rate (HR) and Oxygen consumption (VO_2), when they are optimized individually, the summary of results is produced in Table 4.

Table 4: Optimal Setting and Values of Manual Lifting Task Parameters (Individual Quality Characteristic Optimization)

Response characteristics	Optimal level of MMH task parameters	Significant MMH task parameters	Predicted optimal value of quality characteristics
Oxygen consumption	A1,B2,C1,D1,E1	A, B, C, D, E	6.36 ml/kg/min
Heart rate	A1,B2,C1,D1,E1	A, B, C, D, E	91.50 beats/min

Following is the stepwise procedure for transforming experimental data into utility data.

B. Construction of Preference Scales

i. Preference Scale for HR (Heart Rate)

- X* = Optimal value of HR = 91.51 beats/min (refer Table 4)
- $X_i^{'}$ = Just acceptable value of HR = 146 (All the observed values of HR are less than 146)
- Following equation is obtained from equation 4:

$$P_{HR}=-44.36\times\log\left(\frac{X_{HR}}{146}\right) \quad (6)$$

ii. Preference Scale for VO2 (Oxygen Consumption)

- X* = Optimal value of VO2 = 6.36 ml/kg/min (refer Table 4)
- $X_i^{'}$ = Just acceptable value of VO2 = 21 (All the observed values of VO2 are less than 21)
- Following equation is obtained from equation 4:

$$P_{VO_2}=-17.34\times\log\left(\frac{X_{VO_2}}{21}\right) \quad (7)$$

C. Calculation of Utility Value

Equal weights (1/2 each) have been assigned to the selected quality characteristics assuming all the quality characteristics, are equally important. However, these weights can be varied depending upon the case or user requirements, if any.

The following relation was used to calculate the utility function based upon the experimental trials:

$$U(n,r)=P_{HR}(n,r)\times W_{HR}+P_{VO_2}(n,r)\times W_{VO_2} \quad (8)$$

Where n is the trial number (n = 1,2,3,….,18) and r is the repetition number (r = 1,2,3). The calculated Utility values are shown in Table 5.

Table 5: Calculated Utility Data Based on Responses Heart Rate and Oxygen Consumption

Trial Number	Utility Values			S/N Ratio (dB)
	R1	R2	R3	
1	8.19	7.65	7.76	-17.92
2	4.09	4.75	4.46	-12.95
3	1.15	1.14	1.32	-1.64
4	7.78	7.27	7.70	-17.60
5	3.73	3.49	3.67	-11.21
6	4.24	4.39	4.27	-12.67
7	5.12	4.47	4.42	-13.40
8	2.17	1.97	1.98	-6.22
9	1.18	1.16	1.17	-1.36
10	4.01	4.12	3.79	-11.99
11	4.38	4.66	4.56	-13.12
12	2.30	1.91	2.23	-6.66
13	5.40	5.22	5.28	-14.49
14	4.47	4.03	4.05	-12.44
15	3.19	3.17	3.12	-9.99
16	2.71	2.77	2.65	-8.66
17	1.05	0.99	1.12	-0.45
18	1.10	1.08	0.81	-0.03
R1, R2, R3 = repetitions of experiments against each of the trial conditions				

D. Analysis of Utility Data for Optimal Setting of MMH Task Parameters

The main effects in terms of Utility values for S/N ratio and Raw data (Tables 6 and 7) are plotted in Figure 1. It can be observed from Figure 2 that the 1st Box size (A1), 2nd level of BMI (B2), 1st level of Frequency of lift (C1), 1st level of Load lifted (D1), 1st level of Vertical distance (E1) and 1st level of Asymmetric angle (F1) are expected to yield a maximum values of the utility and S/N ratio within the experimental space.

Table 6: Main Effects of Heart Rate and Oxygen Consumption (S/N Ratio)

LEVEL	Box size	BMI	Frequency of lift	Load lifted	Vertical distance	Asymmetric angle
L1	-10.55	-10.71	-14.01	-10.07	-11.60	-9.73
L2	-8.65	-13.07	-9.40	-9.79	-10.35	-9.40
L3	--	-5.02	-5.39	-8.94	-6.85	-9.67
L2-L1	1.90	-2.35	4.61	0.28	1.25	0.34
L3-L2	--	8.05	4.01	0.85	3.49	-0.27
L1, L2 and L3 represent levels 1, 2 and 3 respectively of parameters. L2-L1 is the average main effect when the corresponding parameter changes from level 1 to level 2. L3-L2 is the average main effect when the corresponding parameter changes from level 2 to level 3.						

Table 7: Main Effects of Heart rate and Oxygen Consumption (Raw Data)

LEVEL	Box size	BMI	Frequency of lift	Load lifted	Vertical distance	Asymmetric angle
L1	4.10	4.03	5.35	4.23	4.42	3.78
L2	3.12	4.69	3.31	3.53	3.68	3.72
L3	--	2.11	2.16	3.07	2.72	3.32
L2-L1	-0.98	0.67	-2.04	-0.70	-0.74	-0.06
L3-L2	--	-2.59	-1.15	-0.46	-0.96	-0.41
L1, L2 and L3 represent levels 1, 2 and 3 respectively of parameters. L2-L1 is the average main effect when the corresponding parameter changes from level 1 to level 2. L3-L2 is the average main effect when the corresponding parameter changes from level 2 to level 3.						

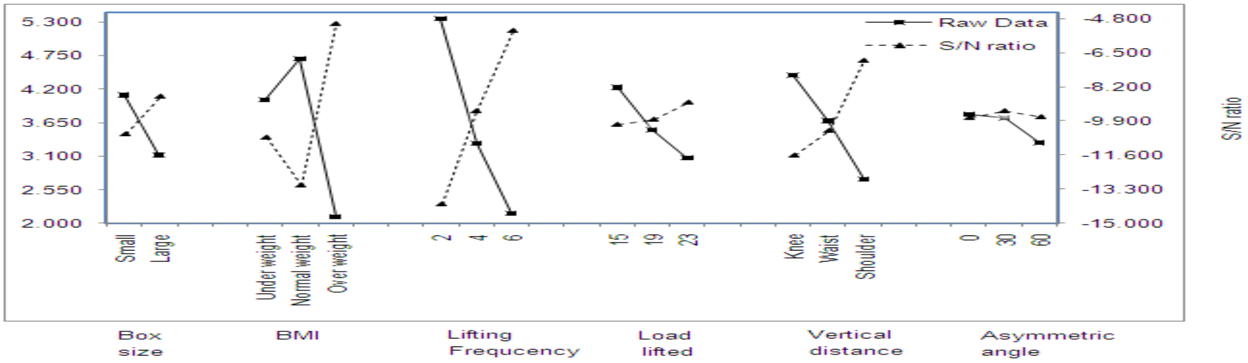

Figure 1: The Main Effects in Terms of Utility Values for S/N ratio and Raw Data

The pooled version of ANOVA of utility values for Raw data and S/N ratio are given in Tables 8 and 9 respectively. It can be noticed from Table 8 that all the input parameters has a significant effect (at 95% confidence level) on the Raw data of utility function. On the other hand, from Table 9 BMI and frequency of lift has significant effect on the S/N ratio of utility function. So, other insignificant parameters for S/N ratio can be taken as economy factor.

Table 8: Pooled ANOVA (Raw data) _ Heart Rate and Oxygen Consumption

SOURCE	SS	DOF	V	F-Ratio	SS'	P %
Box size	13.04	1	13.04	275.29*	12.99	6.06
BMI	64.92	2	32.46	685.17*	64.83	30.22
Frequency of lift	93.85	2	46.92	990.48*	93.75	43.70
Load lifted	12.21	2	6.11	128.91*	12.12	5.65
Vertical distance	26.21	2	13.10	276.60*	26.11	12.17
Asymmetric angle	2.32	2	1.16	24.52*	2.23	1.04
Error	1.99	42	0.05	--	2.51	1.17
Total	214.55	53	--	--	214.5469	100
*Significant at 95% confidence level, F_{Table} (Box size);4.07, F_{Table} (Others);3.22; SS: Sum of squares; DOF: Degree of Freedom; V: Variance; SS': Pure Sum of Squares						

Table 9: Pooled ANOVA (S/N ratio) _ Heart Rate and Oxygen Consumption

SOURCE	SS	DOF	V	F-Ratio	SS'	P %
Box size	16.26	1	16.26	3.65	--	--
BMI	205.35	2	102.68	23.07*	196.45	35.80
Frequency of lift	223.23	2	111.62	25.07*	214.33	39.06
Load lifted	4.20	2	2.10	0.47	--	--
Vertical distance	72.54	2	36.27	8.15*	63.64	11.60
Asymmetric angle	0.39	2	0.19	0.04	--	--
Error	26.71	6	4.45	--	74.27	13.54
Total	548.69	17	--	--	548.69	100
*Significant at 95% confidence level, F_{Table} (Box size);5.99, F_{Table} (Others);5.14; SS: Sum of squares; DOF: Degree of Freedom; V: Variance; SS': Pure Sum of Squares						

E. Optimal Values of Quality Characteristics (Predicted Means)

The average values of all the response characteristics at the optimum levels of significant parameters with respect to Utility function are recorded in Table 10.

The optimal values of the predicted means (μ) of different response characteristics can be obtained from the following equation:

$$\mu = A1 + B2 + C1 + D1 + E1 + F1 - 5T \quad (9)$$

where, A1-First level of Box size, B2- Second level of BMI, C1- First level of Frequency, D1- First level of Load lifted, E1- First level of Vertical distance and F1- First level of Asymmetric angle

The 95% confidence interval of confirmation experiments (CI_{CE}) can be computed [Roy (1990)] by using the following equation:

$$CI_{CE} = \sqrt{F_{\alpha}(1, f_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R} \right]} \quad (10)$$

where, F_{α} (1, f_e) = The F-ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e., R = Sample size for conformation experiments, V_e = Error variance, n_{eff} = $\frac{N}{1+DOF}$, N= total number of trials, and DOF= Total degrees of freedom associated in the estimate of mean response.

i. For Heat Rate (HR)

- $\mu_{HR} = A1 + B2 + C1 + D1 + E1 + F1 - 5T_{HR} = 90.95$

  where A1 = 119.71, B2 = 114.34, C1 = 111.56, D1= 119.61, E1 = 115.54, F1 = 121.75 (Table 10):

Table 10: Average Values of Various Responses at Optimal Levels

Levels	Heart rate (beats/min)	Oxygen consumption (ml/kg/min)
A1	119.71	12.56
B2	114.34	11.59
C1	111.56	10.54
D1	119.61	12.44
E1	115.54	12.47
F1	121.75	12.97
Note:The above average values are taken from experimental Data		

- T_{HR} = 122.31

The following values have been obtained by the ANOVA:

- N = 54, fe = 42; ve = 8.92, neff = 4.5, R= 3, F0.05 (1, 42) = 4.0764
- From equation 10, CI_{CE} = ± 4.49
- The predicted optimal range (for conformation runs of three experiments) for HR is given by
- CI_{CE}: 86.46< μHR <95.44

ii. *For Oxygen Consumption (VO2)*

- $\mu_{VO_2} = A1 + B2 + C1 + D1 + E1 + F1 - 5T_{VO_2} = 6.01$

  where A1 = 12.56, B3 = 11.59, C2 = 10.54, D2= 12.44, E3 = 12.47, F3 = 12.97 (Table 10):
- $T_{vo2} = 13.31$
- The following values have been obtained by the ANOVA:
- N = 54, f_e = 42; v_e = 0.80, n_{eff} = 4.5, R= 3, $F_{0.05}$ (1, 42) = 4.0764
- From equation 10, CI_{CE} = ± 1.34
- The predicted optimal range (for conformation runs of three experiments) for VO_2 is given by
- CI_{CE}:4.67< μ_{VO2}<7.35

VI. CONFIRMATION EXPERIMENT

For confirmation of experimental results, three experiments were performed at optimal settings as suggested by Taguchi analysis of Utility data. The average Heart rate and Oxygen consumption were found to be 93.21bpm and 7.23ml/kg/min, which fall within the 95% CI_{CE} of the optimal range of the respective response characteristic.

VII. CONCLUSION

A simplified model based on the Taguchi method and Utility concept was used to analyze the multi response optimization of MMH tasks. Following conclusions can be drawn from this study:

- A simplified model based on Taguchi's approach and utility concept is used to determine the optimal setting of the MMH tasks parameters for multi-characteristics. The model is used to predict an optimal setting of the MMH tasks parameters to achieve the optimal quality characteristics (Heart rate and Oxygen consumption).

- All the input parameters significantly improve the Utility function comprising of two quality characteristics (Heart rate and Oxygen consumption).

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