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Predictive Thin Plate Spline Model for Estimation of Load Carriage at Varying Gradient and Speed

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ABSTRACT

Laboratory-based experimental studies are being carried out for Indian soldiers to estimate optimal load carriage at different gradients and walking speeds. These experiments involve the recording of Cardio-respiratory responses such as Heart Rate (HR), Oxygen Consumption (VO_2), Energy Expenditure (EE), Respiratory Frequency (RF), Minute Ventilation (VE), and Maximal Aerobic capacity (%VO_{2max}). Due to limitations in the data sample size that can be obtained in laboratory-based experiments, there is a need for mathematical interpolation to obtain intermediate values in the study. Load carriage can be affected by factors that can be controlled, such as the speed of marching, and also by external factors that cannot be controlled like ambient temperature. Real-time interactions of all the factors also have an impact on the load-carrying capacity. Planning of the mission operations requires the specification of well-defined work-rest schedules and indication of total load limits, to ensure the operational effectiveness of the military personnel. In this paper, we present a Predictive 3-Dimensional Thin Plate Spline Model for efficient estimation of load. We developed a Multiple Linear Regression Model for predicting %VO_{2max} for combinations of load and gradient. The accuracy of the model was 85 per cent and the maximum permissible loads were derived from the prediction model for the physiological limits of 50 per cent, 60 per cent, and 75 per cent of VO_{2max}. A Thin Plate Spline based interpolation technique was used on this Multiple Linear Regression Model to generate optimal load at intermediate values for the experimental study. A similar predictive Interpolation Model was also developed for estimating load for varying walking speeds at level ground.

Keywords: Optimal load carriage; Cardio-respiratory responses; Thin plate spline; Gradient; Walking speed

1. INTRODUCTION

One of the focus areas in military-based research is to evaluate the performance of soldiers both quantitatively and qualitatively. Optimal load carriage recommendations for different terrains are essential to ensure combat readiness in soldiers[1]. Uphill trekking with load, indicated increased levels in physiological parameter recordings than during downhill. The experimental analysis presented by an existing research[2] includes walking speed as a parameter, in addition to load and gradient. One interesting observation was that, for speeds of 3.5 and 4.5 $km\ hr^{-1}$, with load 10.7 kgs at 10 per cent gradient, the physiological demand was 47.2 per cent and 64.6 per cent of (Maximal Aerobic Capacity) VO_{2max} respectively. While, at a self-selected walking speed carrying 21.4 kgs load at 15 per cent gradient, the physiological demand was only 34.8 per cent of VO_{2max}. The work carried out on South African soldiers[3] recommended 50 kgs and 35 kgs load at 3.5 and 4.5 $km\ hr^{-1}$ walking speeds respectively. Documented observations[4] conduced on young industrial workers suggest that 35 per cent of VO_{2max} can be used as the recommended work rate. In an existing research paper[5] the altitude, temperature, humidity, and load were taken into consideration. At high altitudes[5], Indian soldiers were advised to walk at moderate speed with a load of more than 32 per cent of their body weight. Sufficient rest in between work was observed to be essential, as the body utilises energy while at rest to maintain body temperature and vital functions such as breathing[10]. The research work also provides insightful observations that the Basal Metabolic Rate (BMR) of the army personnel, is more than that of the normal individual because they have more muscles and dense bones. The relationship between the measured BMR and the recorded variables, such as age, weight, height, Oxygen Consumption (VO_2), Volume of Exhaled Carbon dioxide (VCO_2), were evaluated using linear regression analysis. The two types of load carriage modes used by the military are Compact Mode (CM) and Distributed Mode (DM)[6]. An experimental study was done by calculating the heart rate, VO_2, and energy expenditure for three different cases DM, CM, and no-load. The research findings indicate that, if the loads are placed around the center of gravity of the body then it consumes less energy. It was observed that CM was a better mode of load carriage than DM. In CM mode less change in the physiological parameters was recorded when the gradient of the path was changed. In DM the load carriage ensemble weighed 21.4 kgs and consisted of a backpack (10.7 kgs), haversack (4.4 kgs), and web (2.1 kgs) distributed over different parts of the body and INSAS rifle (4.2 kgs) in hand.

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A linear increase in Heart Rate (HR), Minute Ventilation (VE), VO_2 and Energy Expenditure (EE) with increasing external load was observed and documented[8]. A significant positive correlation r = 0.97 and 0.99 were found at 3.5 and 4.5 *km hr*$^{-1}$ walking speeds respectively. The work presented in an existing publication[8] is the research work to study and recommend optimum load carriage for Indian infantry soldiers. The recommendations for permissible load for carriage at 3.5 and 4.5 *km hr*$^{-1}$ are 36.1 kgs and 21.3 kgs respectively and the details of the study are documented[9]. A detailed study on the kinematics aspects of the gait during load carriage was conducted[7]. It was observed that the impact on the kinematics was due to the adaptive actions by the individual to counterbalance the load effect and speed changes. An existing research work[1] highlights significant interaction effects observed between gradient and load for HR, VO_2, EE, VE, and $\%VO_{2max}$ during load carriage, and these findings correlated with the work documented in a related research publication[11]. Regression analysis was performed using $\%VO_{2max}$ and load at different gradients to estimate the maximum permissible load. According to existing research results[12], for 8-hour workday at 5 per cent and 0 per cent gradients the permissible level is 50 per cent of VO_{2max}, for 2-hour work at 10 per cent gradient permissible level is 60 per cent of VO_{2max} and for 30 minutes of a workday at 10 per cent and 15 per cent gradients permissible level is 75 per cent of VO_{2max}. The objective of the work presented in this paper is to develop a Multiple Regression Model for $\%VO_{2max}$ to enable a comprehensive study of $\%VO_{2max}$, load, gradient/speed using a single predictive model. The work documented in an existing research publication[2] indicates that soldiers can walk for a longer duration carrying different loads at a self-selected walking speed. In this paper, we also present a methodology to find the distance covered by the soldiers for the load and recommended speed limit, to accurately define the tasks that need to be accomplished by the army personnel. However, the primary motivation is to be able to analyse the prediction accuracy of the proposed Thin Plate Spline Interpolation Model for the estimation of permissible loads. The assumption here is that laboratory-based data samples for load carriage are difficult to obtain due to the time availability of soldiers and the physical limitations of the experiment itself. Hence a mathematical model is proposed to overcome the challenges in estimating the recommended load.

In the next section, factors related to load-carriage analysis are discussed followed by the section containing details of the proposed Multiple Regression Model. The Thin Plate Spline Interpolation Model for varying load and gradient is introduced next, followed by the Multiple Regression Model for speed.

2. METHODOLOGY

2.1 Load Carriage Prediction Model

Cardio-respiratory factors associated with load carriage[1] are as follows:

- Heart Rate (HR) (*beats min*$^{-1}$)
- Oxygen Consumption (VO_2) (*ml min*$^{-1}$ *kg*$^{-1}$)
- Respiratory Frequency (RF) (*breath min*$^{-1}$)
- Energy Expenditure (EE) (*kcal min*$^{-1}$)
- Minute Ventilation (MV) (*l min*$^{-1}$)
- Maximal Aerobic Capacity (% VO_{2max}) (*ml min*$^{-1}$ *kg*$^{-1}$)

The documented experimental study[1] involves ten physically fit infantry soldiers of the Indian army with mean values - age 23.2 years, height 172.6 cm, weight 65.9 kg, and max aerobic capacity 47.5 per cent of VO_{2max}. The soldiers were asked to walk at 4.5 *km hr*$^{-1}$ speed on a treadmill carrying loads of different weights on various gradients. The cardio-respiratory measurements were obtained and the dataset is available in the public domain[1]. However, the analysis presented in the paper, to estimate the optimum or maximum permissible load, was based on the inferences from Simple Regression analysis between $\%VO_{2max}$ and load for different gradients. Hence, four Simple Linear Models were generated to estimate the load for $\%VO_{2max}$. But the drawback is that the load recommendation for a particular $\%VO_{2max}$ value can only be obtained for a fixed gradient. The motivation for the work presented in this paper is to generate a single Multiple Linear Regression Model to find the value of $\%VO_{2max}$ at any gradient and weight of the load carried.

2.2 Multiple Regression Model for Estimation of Load carriage

The relationship of % VO_{2max} with load and gradient can be expressed mathematically as follows Eqn. (1):

$$L=f(\%VO_{2max}, G, \epsilon) \tag{1}$$

where

- $\%VO_{2max}$ represents Maximal Aerobic Capacity
- L represents the weight of the load carried by soldiers
- G represents the gradient as per cent of inclination
- ϵ represents the measurement error

As ϵ is based on random factors, the determination of the above relationship can be done using appropriate statistical methods. Further, $\%VO_{2max}$ and gradient are independent of load and hence multiple regression can be used to model the function. From domain knowledge, we can assume that load and gradient have a linear relationship with $\%VO_{2max}$. The following assumptions are made about ϵ:

- ϵ are uncorrelated
- ϵ are normally distributed

With these assumptions the general form of the model can be considered as Eqn. (2):

$$L=\beta_0+\beta_1\%VO_{2max}+\beta_2 G+\epsilon \tag{2}$$

The estimates of the intercept term (β_0) and the regression coefficients (β_1 and β_2) are obtained from the documented data[1] and presented in Table 1 for reference.

The Multiple Linear Regression (MLR) Model 1 is presented below Eqn. (3):

$$\hat{L}=-33.124+1.470\%VO_{2max}-4.909G \tag{3}$$

The test for significance of the regression is a study to determine if there is a linear relationship between the response (load) and any of the predictor variables ($\%VO_{2max}$ and gradient). This procedure is often thought of as an overall or global test for model adequacy. Appropriate hypotheses are

```
Call :
lm(formula = Load  ~  vo2max + Gradient, data = mydata)
Residuals :
     Min     1Q   Median      3Q     Max
-8.0253 -2.0723  0.9067  2.1864  4.8509

Coefficients :
             Estimate std. Error t value pr(> I t I)
(Intercept)  -33.1243     4.6894    -7.064  1.90e-06 ***
vo2max         1.4696     0.1516     9.695  2.43e-08 ***
Gradient      -4.9086     0.5236    -9.375  3.95e-08 ***
---
Signif. codes :    0  '***'  0.001  '**'  0.01  '*'  0.05  '.'  0.1  ' '  1

Residual standard error :  3.334  on 17 degrees of freedom
Multiple R-squared :  0.8468,    Adjusted R-squared :   0.8288
F-statistic :  46.99  on  2  and 17  DF,   p-value: 1.186e-07
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Figure 1. Screenshot of Model 1 summary.

formulated Eqn. (4) and the process involves testing the Null Hypothesis[13]. The hypotheses are:

$$H_0 : \beta_1 = \beta_1 = 0 \; versus \; H_1 : \beta_j \neq 0 \tag{4}$$

where H_0 is the Null Hypothesis and H_1 is the Alternative Hypothesis for some j = 1, 2. To test the Null hypothesis, we need to be confident that β_1 and β_2 are non-zero.

From the model summary presented in Fig. 1, it can be observed that the value of the test F-statistic is 46.99 and the sampling distribution under H_0 is $F_{2,17}$. The *p*-value is the probability of observing any value equal to |F| or larger, assuming $\beta_1 = \beta_2 = 0$. The significance factor represented by the *p*-value is 1.186 X 10^{-7}, which is small and hence it reveals that there is an association between the predictor and the response. This indicates that the data has sufficient evidence

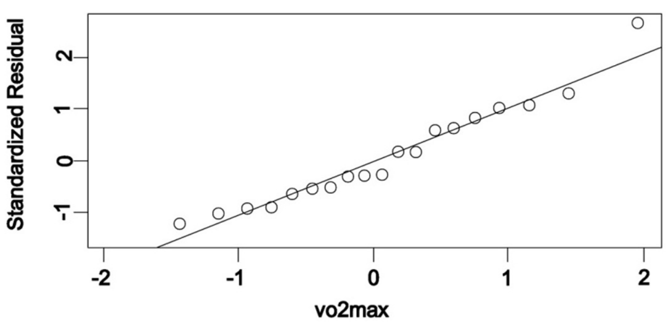

Figure 2. Graphical representation of the normally distributed residuals of $\%VO_{2max}$.

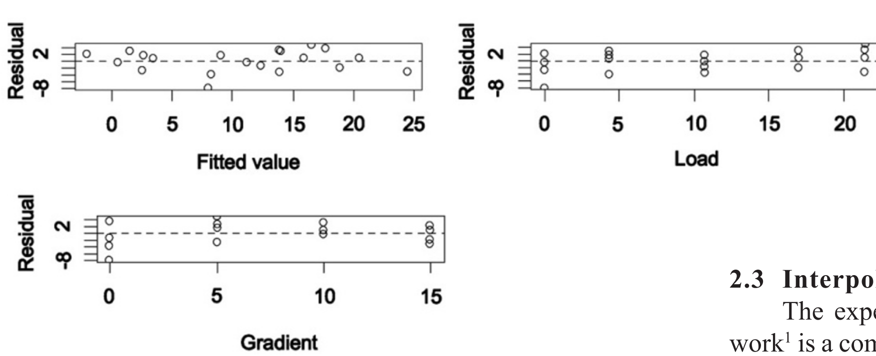

Figure 3. Plots of residuals versus fitted values and load and gradient show the distribution of residuals is normal.

for the rejection of H_0. It highlights that the linear relationships of $\%VO_{2max}$ with L and G are significant. In favour of H_1, it is natural to quantify the extent to which the model fits the data. It points out that 84.68 per cent of the variation in load is explained by the MLR estimated Model 1. The hypotheses for testing the significance of each regression coefficient in MLR Model 1, such as β_j are (5):

$$H_{0j} : \beta_j = 0 \; versus \; H_{1j} : \beta_j \neq 0 \quad \text{for some } j = 0,1,2 \tag{5}$$

If H_{0j} is not rejected, then this indicates that the predictors can be deleted from the model. The sampling null distribution of test statistics in each case is the *Student's* t_{17} distribution. The significance value of *p* (type 1 error) presented in Fig. 2, in each case is very small, 1.90 x 10^{-6} for rejection of H_{00}, 2.43 x 10^{-8} for rejection of H_{01}, and 3.95 x 10^{-8} for rejection of H_{02}. The hypotheses results emphasise the significance of the estimated model and its estimated coefficients. The estimated model can be used for further analysis only after verifying whether it satisfies the assumptions made on the error term (ϵ). The residuals, $\epsilon_i = \%VO_{2max_i}\%VO_{2max_i} - \%\widehat{VO_{2max_i}} \%\widehat{VO_{2max_i}}$, i = 1,...,20 are computed and analysed. Figure 2 displays the plot of the residuals that helps to infer whether they are normally distributed. Except for a few points, all other points lie very close to the diagonal line. This shows that there is large evidence for deciding that the approximate distributions of the residuals are normal and Fig. 3 also highlights this. The normality assumption of the error term is further investigated by carrying out the following statistical tests: Anderson Darling test and Kolmogorov-Smirnov test.

In each of these tests, the hypotheses tested are

H_{03}: This fit is good (i.e) e ~ normal
versus H_{13}: The fit is not appropriate

On applying the Anderson-Darling test, the value of test statistics was calculated as 1.9448 and, the *p*-value was 0.0991. Whereas, the value obtained from the Kolmogorov-Smirnov test-statistic was 0.2081 with a *p*-value of 0.3072. Both the tests do not provide sufficient evidence for the rejection of the normality assumption. Hence, it may be concluded from the analysis of residuals and residual plots that the estimated model satisfies the assumptions of the model. Therefore, the estimated model can be considered adequate to conduct further investigation on the relationship of $\%VO_{2max}$ with load and gradient.

2.3 Interpolation Technique

The experimental data provided in an existing research work[1] is a combination of five different loads and four different gradients. This data set has been presented here for reference in Table 1. Using the Multiple Linear Regression Model 1, values for other combinations of load and gradient can be determined. But this approach does not provide good accuracy. To extend the scope of the experimental data that is limited to a few combinations of load and gradient, mathematical interpolation techniques can be used. Using the known data values an estimation of the unknown data points in the range of the known data is done by interpolation.

Thin-Plate Splines (TPS)[14] used in this research work are spline-based techniques for data interpolation and smoothing.

Table 1. Original data set for gradient

Parameter	Load (Kg)	Gradient (%)			
		0	5	10	15
$\%VO_{2\,max}$	0	28.0	41.0	56.3	71.3
	4.4	28.2	41.1	57.0	75.0
	10.7	31.0	45.4	63.6	82.1
	17	32.0	48.8	66.8	85.5
	21.4	34.6	50.5	69.9	86.8

Table 2. Original dataset for speed

Load (Kg)	VO_{2max}	Speed
0	20.3	3.5
4.4	23.2	3.5
10.7	24	3.5
17	29.6	3.5
21.4	31.1	3.5
32.5	32.4	3.5
40	36	3.5
0	28	4.5
4.4	28.2	4.5
10.7	31	4.5
17	31.9	4.5
21.4	34.6	4.5
32.5	40	4.5
40	42.3	4.5

In this paper, R programming was used to generate the interpolation model. In R, splines are fitted using Generalised Additive Models and Generalised Additive Mixed Models using the *"mgcv"* package[15]. A Thin Plate Spline (TPS) 3D model was generated to find the optimum load using interpolation. This was done using two approaches. In the first approach, the data-set in Table 1 and the MLR Model 1 was used to predict intermediate values by fixing the $\%VO_{2max}$ and varying the gradient. In the second approach, again the data-set in Table 1 and Model 1 were used to predict the intermediate values separately by varying the $\%VO_{2max}$ and fixing the gradient.

2.4 Multiple Regression Model for Estimation of Speed for $\%VO_{2max}$

As discussed in Section 2.2, similarly the relationship of $\%\ VO_{2max}$ of soldiers with load and speed can be expressed mathematically as follows Eqn. (6):

$$S = f\,(\%VO_{2max}, L, \epsilon) \tag{6}$$

where

- $\%VO_{2max}$ represents Maximal Aerobic Capacity
- L represents the weight of the load carried by soldiers
- S represents the walking speed of soldiers
- ϵ represents the measurement error

As ϵ is based on random factors, the determination of the above relationship can be done using appropriate statistical methods. Further, $\%VO_{2max}$ and load are independent of speed and hence Multiple Regression can be used to model the function. The following assumptions are made about ϵ:

- ϵ are uncorrelated
- ϵ are normally distributed

With these assumptions the general form of the model can be considered as Eqn. (7):

$$S = \beta_0 + \beta_1 \%\ VO_{2max} + \beta_2 L + \epsilon \tag{7}$$

The estimates of the intercept term (β_0) and the regression coefficients (β_1 and β_2) are obtained from documented data[8] and presented in Table 2 for reference. The Multiple Linear Regression (MLR) Speed Model is presented below (8):

$$\hat{S} = 0.238 + 0.156\%VO_{2max} - 4.909G \tag{8}$$

The summary of the Speed Model is presented in Fig. 4. The test for significance of the regression is a study to determine if there is a linear relationship between the response (speed) and any of the predictor variables ($\%VO_{2max}$ and load). This procedure is often thought of as an overall or global test for model adequacy. Appropriate hypotheses are formulated and the process involves testing the Null Hypothesis as described here. The hypotheses are (9):

$$H_0 : \beta_1 = \beta_1 = 0 \ \textit{versus}\ H_1 : \beta_j \neq 0 \tag{9}$$

where H_0 is the Null Hypothesis and H_1 is the Alternative Hypothesis for some j = 1, 2. To test the Null hypothesis, we

```
Call :
lm(formula = Speed  ~  vo2max + Load, data = mydata)
Residuals :
     Min       1Q    Median        3Q      Max
-0.35618 -0.09339  0.03771  0.12125  0.28429

Coefficients :
             Estimate std. Error t value pr(> I t I)
(Intercept)  0.238856  0.428069   0.558     0.588
vo2max       0.156317  0.017418   8.975  2.15e-06 ***
Load        -0.059391  0.007672  -7.741  8.91e-06 ***
---
Signif.  codes :   0  '****'  0.001  '***'  0.01  '*' 0.05 '.' 0.1 ' ' 1

Residual standard error :  0.1955  on 11 degrees of freedom
Multiple R-squared :  0.8798,    Adjusted R-squared :   0.858
F-statistic :  40.27  on  2  and 11  DF,  p-value: 8.683e-06
```

Figure 4. Screenshot of speed model summary.

need to be confident that β_1 and β_2 are non-zero. From the model summary presented in Fig. 4, the value of the test F-statistic is 40.27 and the sampling distribution under H_0 is $F_{2,11}$. The *p*-value is the probability of observing any value equal to |F| or larger, assuming $\beta_1 = \beta_2 = 0$. Since, the significance factor represented by *the p*-value is 8.6 X 10^{-6}, which is small, it reveals that there is an association between the predictor and the response. This indicates that the data has sufficient evidence for the rejection of H_0. It highlights that the linear relationships of $\%VO_{2max}$ with L and S are significant. In favor of H_1, it is natural to quantify the extent to which the model fits the data. The overall adequacy of the estimated model can be justified with the coefficient of determination R-squared = 0.858. It points out that 85.8 per cent of the variation in load is explained by the MLR estimated Speed Model. The hypotheses for testing the significance of each regression coefficient in the MLR Speed Model, such as β_j are Eqn. (10):

$$H_{0j} : \beta_j = 0 \textit{ versus } H_{1j} : \beta_j \neq 0 \quad \text{for some } j = 0,1,2 \tag{10}$$

If H_{0j} is not rejected, then this indicates that the predictors can be deleted from the model. The sampling null distribution of test statistics in each case is the *Student's* t_{17} distribution. The significance value of *p* (type 1 error) presented in Fig. 4, in each case is very small, 0.588 for rejection of H_{00}, 2.15 x 10^{-6} for rejection of H_{01}, and 8.91 x 10^{-6} for rejection of H_{02}. Hence, it may be concluded from the analysis of variance that the estimated Speed Model satisfies the assumptions of the model.

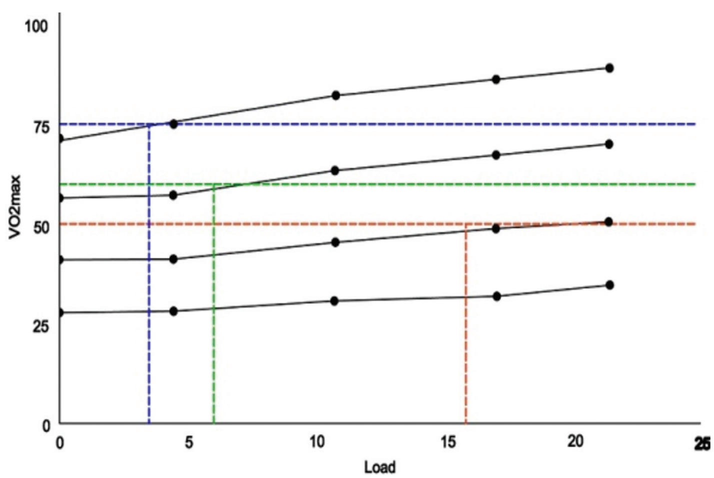

Figure 5. Relationship between percentage of VO_{2max} and load.

Table 3. Estimated optimum load

Work duration (hours)	Gradient(%)	Estimated Optimum Load (in kg)
8	0	55.07
8	5	15.8
2	10	5.98
0.30	10	28
0.30	15	3.49

Therefore, the estimated Speed Model can be considered adequate to conduct further investigation.

3. RESULTS AND DISCUSSION

The load carriage by soldiers may be estimated for different gradient levels of surface on substituting 50 per cent, 60 per cent, and 75 per cent of VO_{2max} in MLR Model 1. The load carriage estimated from MLR Model 1 is presented in Fig. 5. The estimated optimum loads at four different gradients are presented in Table 3. It may be noted that these findings are subject to the level of appropriateness of the estimated model, which may be computed as 1 – 1.186x10^{-7} ~ 1 and it holds uniformly for other different levels of gradients.

The analysis presented in an existing research work[1] estimated the load carriage using separate models corresponding to different gradient levels. Accordingly, new models should be developed for other levels of gradient corresponding to which load has to be estimated. The level of appropriateness of the model may not be uniform and hence the appropriateness of different load carriages will vary. It shows an inconsistency in the suitability of estimated load carriages. The methodology proposed in this paper can overcome such inconsistencies. The data-set contains three parameters - load, gradient, and % VO_{2max}.

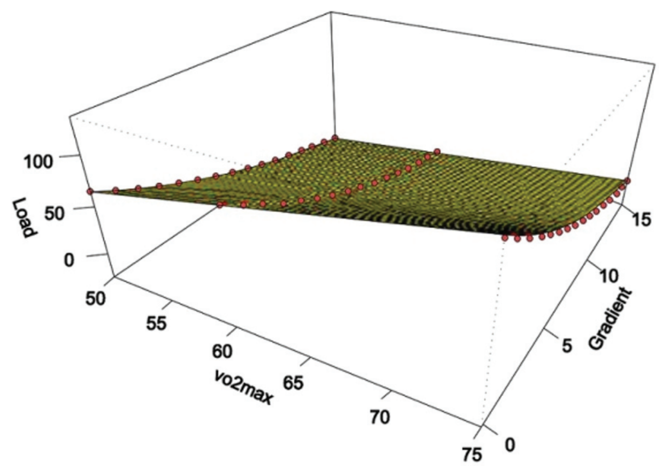

Figure 6. Model 2 – VO_{2max} Vs gradient Vs load.

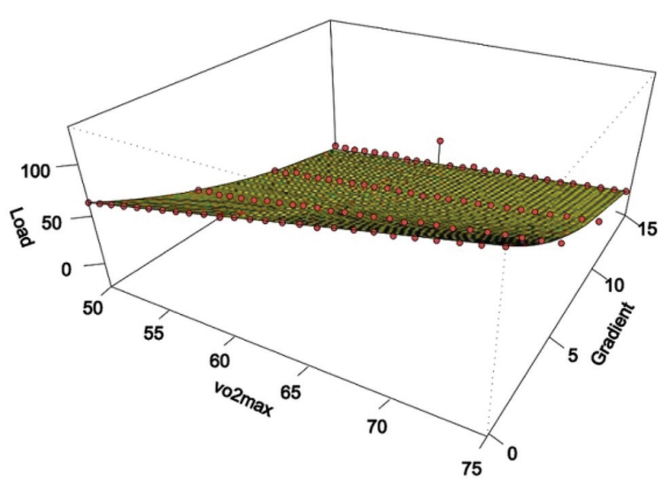

Figure 7. Model 3 – VO_{2max} Vs gradient vs load

Gradient(%) varies from 0 to 15 with an incremental value of one and $\%VO_{2max}$ is assigned values 50, 60, and 75. This generates 48 different values in the new data set. For any different gradient and $\%VO_{2max}$, the appropriate load is found using the Multiple Linear Regression Interpolation Model 2. The 3D Thin Plate Spline which generates Model 2 is shown in Fig. 6. The data-set contains three parameters load, gradient, and $\%VO_{2max}$. Gradient(%) is 0, 5, 10, and 15, and $\%VO_{2max}$ varies from 50 to 75 with an incremental value of one and the new data-set thus contains 104 different combinations. For any different gradient and $\%VO_{2max}$, the appropriate load is found using the generated Model 3 shown in Fig. 7.

The optimum loads estimated at four different gradients using the Multiple Linear Regression Interpolation Model 3 are presented in Table 4. According to the documented results[12] for 8-hour workday at 5 per cent and 0 per cent gradients the permissible level is 50 per cent of VO_{2max}, for 2-hour work at 10 per cent gradient permissible level is 60 per cent of VO_{2max} and for 30 minutes of a workday at 10 per cent and 15 per cent, gradient permissible level is 75 per cent of VO_{2max}. Thus the results of Table 4 can be interpreted and used to specify load carriage norms for Indian soldiers.

Table 4. Estimated optimum load

Work duration (hours)	Gradient (%)	Estimated optimum load (in kg)
8	0	64.7
8	5	20.3
2	10	6.7
0.30	10	28.8
0.30	15	3.9

Table 5. Distance comparison

Load (kg)	$\%VO_{2max}$	Speed (km hr^{-1})	Distance Covered (meter)
	20.3	3.4	170
0	28.0	4.6	230
	20.1	3.4	170
	24.0	3.3	165
10.7	31.0	4.4	220
	22.2	3.07	153
	31.1	3.8	190
21.4	34.6	4.3	215
	24.3	2.74	137

The values of $\%VO_{2max}$ while walking at a fixed speed of 3.5 *km hr^{-1}* are substituted in our Speed Model and the estimated speed (S_1) is computed and the residues (R_1=3.5-S_1) are calculated. Then the values of $\%VO_{2max}$ while walking at a fixed speed of 4.5 *km hr^{-1}* is substituted in our Speed Model and estimated speed (S_2) and corresponding residues (R_2=4.5-S_2) are calculated. The distance covered by each soldier walking at a particular speed for a time duration of three minutes is calculated so that from the maximum distance covered, the optimal speed limit for maximizing work outcome can be suggested. In Table 5 we present the distance covered, for three different loads (0, 10.7, 21.4) (in kg) with three different $\%VO_{2max}$ for each load, corresponding to three different walking speeds (3.5, 4.5 *km hr^{-1}* and self-selected). From these results, we can infer that at 4.5 *km hr^{-1}* the soldiers can cover the maximum distance for all categories of loads.

4. CONCLUSION

This paper presents a methodology to extend the scope of laboratory-based experimental studies involving physiological measurements under varying conditions of load and gradients. The research work presented in an existing research work[1] uses four simple linear regression models to recommend the optimum load for different gradient values using the physiological parameters recorded during the laboratory study. However, only certain combinations of load and gradients could be utilised for data capture due to physical limitations. The interpolation models presented in this paper were proposed to overcome the limitations through mathematical modeling. The physiological parameter $\%VO_{2max}$ was used in our study but similar modeling techniques could be extended to all other parameters as well. The work also involves the integration of speed as a factor in the model using the data-set provided in an existing research publication[2]. From the research results, the recommended speed for optimal work outcome is 4.5 *km hr^{-1}* for all categories of load. The Multiple Linear Regression and Interpolation Model presented in this paper would help to generate an accurate prediction for values that were not obtained during laboratory-based data capture.

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In the current study she was involved in review of literature, data analysis, providing scientific inputs and manuscript preparation.