

1 **Parametric Investigation and Optimization of the Newly Developed Pant**
2 **Loading Ramp Machine**

3
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10 **ABSTRACT**

11 Objective of the current study was to optimize newly developed pant loading ramp to perform
12 manual handling task. Pant loading ramp was 19 feet in length, having width of 2 feet, anti-
13 slippery, easy to move due to provision of rotating wheels, adjustable at varying heights of
14 the loading vehicle (between 2.5-5 feet) and reduces the loading time up to 30 minutes. For
15 this purpose experiments were conducted on a group of 20 experienced manual handlers in
16 rice mills of Udham Singh Nagar district, Uttarakhand, India. The reliability and validity of
17 the developed, loading ramp was assessed by using response surface methodology in terms of
18 change in energy expenditure (EE), rate of perceived exertion (RPE), total cardiac cost of
19 work (TCCW) and grip strength (GS). Therefore **Response Surface Methodology (statistical**
20 **tools to determine the significance of a factor over a response or collection of mathematical**
21 **and statistical techniques for empirical model building)** was applied to optimize the
22 operating parameters of ramp such as load weight, height of ramp and time. As per Box
23 Behenken design total 17 experiments were carried out each of which varied over three
24 levels as load weight (40, 50 and 60 kg.), height of ramp (3, 4 and 5 feet), and time (3, 4
25 and 5 min.). ANOVA and coefficient of determination (R^2) test were applied. In result it
26 was observed that use of pant loading ramp was able to reduce **Energy Expenditure (EE)** of
27 respondents' from 14.55 kJ/min. to 11.41 kJ/min., **Rate of Perceived Exertion (RPE)** from
28 85.45 to 20 %, **Total Cardiac Cost of Work (TCCW)** from 996.3 to 564.36 beats and **Grip**
29 **Strength (GS)** from 47.45 to 3.30 % with overall desirability of 0.84 %. In comparison

30 with traditional method it was also found to reduce Average Working heart Rate (AWHR)
31 (14.55-11.41), Peak Energy Expenditure (PEE) (16-12), Rate of Perceived Exertion
32 (RPE) (85.45-20), Grip Strength (GS) (47.45-3.30) and Total Cardiac Cost of Work
33 (TCCW) (996.3-564.35). Relative advantages showed that more than 95 % users were
34 highly satisfied and found it advantageous.

35 Key-words: Musculoskeletal disorders ergonomics volume of oxygen uptake

36 INTRODUCTION

37 According to Genaidy *et al.* (2003¹) operations related to manual handling include the
38 acts of lifting, lowering, carrying, pushing, pulling, and holding items. National Institute for
39 Occupational Safety and Health, 1997 reported that when handling and lifting items
40 manually, there is always potential for injuries such as strains, sprains, fractures, cuts, lower
41 back pain due to awkward postures, muscle fatigue and **musculoskeletal discomforts (MSDs)**
42 problems. Among the injuries reported in industry, MSD have been recognized as one of the
43 leading problem. **Besides these, researches also show** a significant linkage between
44 musculoskeletal injuries and manual handling (Edlich *et al.*, 2005²; Hoozemans *et al.*, 1998³).
45 It is found that manual handling injuries are a major burden to society, organizations and the
46 sufferers **themselves. The financial costs of manual handling injuries are estimated to be in**
47 **the region of £2 billion a year.**

48 Recent statistics from the Health and Safety Authority (2007⁴) indicate that, approximately
49 one third of all reported work-related incidents are triggered by manual handling. The
50 proportion of incidents associated with manual handling is particularly high in the wholesale
51 and retail trade (47 %), manufacturing (40 %) and health and social care (38 %). The most
52 common type of injury in 2006 was 'physical stress or strain to the body' (41 %) and the
53 most frequently injured body part was the back (24 %). Health and related occupations are

54 ranked sixth in the ‘top 10 occupations of workers injured’ (Health and Safety Statistics,
55 2012⁵).

56 However workers in the rice mill industry have a high risk of musculoskeletal
57 disorders because they are principally involved in manual material handling (MMH) task.
58 Although today the tasks or processes of industries are being mechanized, but many are still
59 tasks are performed manually in the rice mills and the worker were sufferings from hazards
60 like, force, awkward postures and repetitive motions that can lead to injuries, energy and time
61 waste. Furthermore it was noted that rice mill workers were using the wooden plank for
62 loading and unloading task which was narrow, short, non static and slippery. It was adjusted
63 on different loading vehicle by using a drum which takes approx 35 min of time period. To
64 avoid these problems, need was felt to redesign and develop a new loading ramp
65 ergonomically which was able to reduce the drudgery of rice mill workers. To test the
66 validity and reliability of pant loading ramp response surface methodology (RSM) was used.
67 Thus the objectives of the present study were to verify the newly developed pant loading
68 ramp by using the RSM statistical technique and to evaluate the relative advantages.

69 MATERIALS AND METHODS

70 In this study, the researcher observed the prevailing working environment and tool
71 (wooden plank) for a period of 1 year that was used by the workers. After detailed analysis of
72 wooden plank and it’s functionality an urgent need was felt to redesign and development of a
73 new pant loading ramp. Thus newly developed pant loading ramp (length of 19 feet, width of
74 2 feet and adjustable between 2.5-5 feet) was statistically tested by conducting the
75 experiments of RSM technique and thereafter its acceptability was rated by taking the
76 responses of workers. To fulfil this objective subjects were familiarized with the
77 experimental procedure and some personal and physiological variables of the workers were

78 also taken. For this study ethical approval was taken from ethical committee of G.B. Pant
79 University of Agriculture and Technology, Pantnagar, Uttarakhand, India.

80 **Subjects:** A group of 20 male subjects were recruited. These workers met the following
81 criteria a minimum of 5 year experience, age between 20-30 years, a low lifetime incidents of
82 injuries, involve in loading and unloading of rice sacks and had a good physical fitness. All
83 subjects were belonging to the very low socio-economic status and never received any
84 ergonomic training.

85 **Locale:** Study was done in the rice mills of Rudrapur block; district Udham Singh Nagar,
86 Uttarakhand, India.

87 **Response surface methodology (RSM) analysis through box behenkan experiment** 88 **design**

89 Response surface methodology (RSM) is a collection of mathematical and statistical
90 techniques for empirical model building by careful design of experiments (Sampaio *et al.*,
91 2006⁶). The objective of RSM is to optimize a response (output variable) which is influenced
92 by several independent variables (input variables) (Alvares, 2000⁷), (Natarajan *et al.*, 2011⁸).
93 Hence, RSM technique was applied to test the efficacy of developed pant loading ramp in
94 terms of energy expenditure (EE), rate of perceived exertion (RPE), total cardiac cost of work
95 (TCCW) and grip strength (GS). Thus to conducting RSM analysis of the loading ramp, the
96 selected process variables (load weight, height of ramp and time) were varied up to three
97 levels. Load weight varied as 40, 50 and 60 kg., height of the ramp as 3, 4 and 5 feet and
98 time was also varied as 3, 4, and 5 min. (Table 2). The Box Behenken design was used for
99 modelling of experiments, where total seventeen experiments were conducted (Table 5).

100 The selected responses were energy expenditure (EE), total cardiac cost of work
101 (TCCW), rate of perceived exertion (RPE) and grip strength (GS) (Table. 3) that were
102 measured by using the formula and scales described below:

103 **Energy Expenditure (EE) (kJ/min) = 0.159X HR (beats/minute)–8.72**

104 **Total Cardiac Cost of Work (TCCW) = CCW+ CCR**

105 Cardiac Cost of Work (CCW) = AHR x Duration

106 Cardiac Cost of Recovery (CCR) = (Average Recovery HR - Average Resting HR) X
107 Duration.

108 **Grip strength (GS):** Grip Strength was measured with the help of Digital Grip
109 Dynamometer. It consists of a handle for handgrip connected with a spring to a pointer on the
110 marked dial. The grip fatigue was measured by asking the subject to pull the grip handle
111 before the start of the activity with right and left hand respectively and readings on the dial in
112 kgs were recorded. Similar procedure was repeated immediately after the completion of the
113 activity. Percentage decrease or increase in grip strength was calculated by the following
114 formula.

$$115 \quad \text{Grip Strength (\%)} = \frac{Sr - Sw}{Sr} \times 100$$

116 Sr = Strength of muscle at rest and Sw = Strength of the muscle at work

117 **Rate of Perceived Exertion (RPE):** For measuring RPE Borg 5-point scale (**Borg (1998⁹)**)
118 was used. i.e., very light –1, light-2, moderately heavy-3, heavy-4, very heavy-5.

119 Thereafter optimized experiments were designed with the help of design expert 8.06
120 software. Besides this surfur software 9.0 was also employed for the graphical optimization
121 of the multiple responses. The table, 1, 2, 3 and 4 showed the selected parameters of the study
122 as constant, independent, dependent and process variables with their levels.

123 **Table 1: Constant parameters for optimization**

SI. no.	Parameters	Value/name
1	Back loading	-
2	Ramp length (16)	Feet

124 **Table 2: Independent variables for optimization**

SI. No.	Parameter	Level	Range
1	Load weight (kilogram)	3	40, 50, 60
2	Height (feet)	3	3, 4, 5
3	Time (minute)	3	3, 4, 5

125 **Design of experiment**

126 Design of experiment is required to extract meaningful conclusions from the
 127 measured responses Therefore, the experimental design was performed with the help of
 128 design expert 8.06 software and brainstorming approach as shown in Table 4 and 5.

129

130 **Table 3: Dependent variables for optimization**

SI. No.	Parameter	Value/name
1	EE (Energy Expenditure)	kJ/min.
2	RPE (Rate of Perceived Exertion)	%age
3	TCCW (Total Cardiac Cost of Work)	Beats
4	GS (Grip Strength)	%age

131

132 **Table 4: Process variable and their levels**

Independent variable Name	Code	Codes level		
		-1	0	1
		Actual level		
Load weight (kilogram)	X ₁	40	50	60
Height of ramp (feet)	X ₂	3	4	5
Time (minute)	X ₃	3	4	5

133

134 **Table 5: Experimental designs**

Std	Run	Factor X ₁ Load weight (kg.)	Factor X ₂ Height of ramp (feet)	Factor X ₃ Time (minute)
1	17	-1.00	-1.00	0.00
2	14	1.00	-1.00	0.00
3	6	-1.00	1.00	0.00
4	13	1.00	1.00	0.00
5	15	-1.00	0.00	-1.00
6	16	1.00	0.00	-1.00
7	2	-1.00	0.00	1.00
8	7	1.00	0.00	1.00
9	1	0.00	-1.00	-1.00
10	3	0.00	1.00	-1.00
11	10	0.00	-1.00	1.00
12	8	0.00	1.00	1.00
13	9	0.00	0.00	0.00
14	5	0.00	0.00	0.00
15	11	0.00	0.00	0.00
16	12	0.00	0.00	0.00
17	4	0.00	0.00	0.00

135 **Coded value (CV):** $\frac{x - \text{mid value (centre point)}}{\text{Difference (internal gap)}}$ Eqn. 1

136 **Eqn. 1 showed about the method of calculating coded value**

137 Besides response surface methodology, comparative performance evaluation and relative

138 advantages of pant loading ramp was also assessed by using a developed interview schedule

139 that includes the questions regarding the concept of drudgery reduction, adjustability, anti-
140 slippery, strength and easy handling of loading ramp. Responses were recorded in Yes or No
141 form.

142

143 **RESULTS AND DISCUSSION**

144 **General characteristics of selected rice mill workers**

145 The general characteristics of selected workers for the RSM experiments revealed that
146 the mean±SD of age, height, body weight, body mass index of workers were calculated as
147 29.03±4.23 years, 162±12.67 cm., 53.65±9.28 kg, and 20.84 ±3.41. The mean±SD of aerobic
148 capacity based on heart rate, BP, pulse rate and body temperature was 39.45 ±5.67 L/min.,
149 117.53/72.15±12/8.4 (systolic/diastolic), 76.54±7.56 beats/min. and 96.50 ±2.6⁰F. Calculated
150 MSD rate was 85.45% by using Nordic questionnaire (Kuroinka *et al.*, 1987¹⁰).

151 **Design and development of pant loading ramp**

152 After need assessment, pant loading ramp was ergonomically designed and developed
153 to reduce the drudgery of rice mill workers which was made of wood and aluminium sheet
154 (small hole were mounted on aluminium sheet). It was 19 feet in length, having width of 1.5
155 feet, anti-slippery, easy to move due to provision of rotating wheels, adjustable at varying
156 heights of the loading vehicle (between 2.5-5 feet) and reduces the loading time up to 30
157 minutes. Finally it was found that the designing of loading ramp reduces the preparation time
158 and delivers maximum output with minimum time (Plate 1). In terms of tool designing,
159 Koivunen (1994¹¹) reported that the redesign of the tool must base on the problem analysis
160 and user-centered design (Kardborn, 1998¹²; Pheasant, 1996¹³) that also provide a good basis
161 for judgement (Sperling *et al.*, 1993¹⁴; Kumar, 1994¹⁵).

162 **Optimization of process parameters using response surface methodology (RSM)**

163 In this study the RSM was applied to optimize the operating parameters (load
 164 weight, height of ramp and time) considered during the experiment. ANOVA test was
 165 applied to evaluate the adequacy (by applying the lack-of-fit test) of different models and to
 166 evaluate the statistical significance of the factors in the model. In order to examine the
 167 goodness and evaluate the adequacy of a fitted model, the coefficient of determination (R^2)
 168 was calculated. Thereafter surfer software 9.0 was used for the graphical optimization of
 169 interaction of selected dependent and independent variables (Pishgar *et al.*, 2012¹⁶).



174 **Front View**

Internal view

Top view

Side view

175 **Plate 1: Different views of improved loading ramp**

176 **Development of second order model**

177 A complete second mathematical model (Eqn 1) was fitted to the data and adequacy
 178 of the model was tested considering the coefficient of multiple determinations (R^2), Fisher's
 179 F-test and lack of fit. The model was used to interpret the effect of load weight, ramp height
 180 and time of load carrying on back on various responses (Table 6) energy expenditure (EE),
 181 rate of perceived exertion (RPE), total cardiac cost of work (TCCW) and grip strength (GS).
 182 The second order mathematical response function for three independent variables has the
 183 following general form:

$$y = B_0 + \sum_{i=1}^3 B_i x_i + \sum_{i=1}^2 \sum_{j=i+1}^3 B_{ij} x_i x_j + \sum_{i=1}^3 B_{ii} x_i^2 \quad \text{Eqn. 1}$$

184 Experimental data were analyzed by employing multiple regression technique to
 185 develop response functions and variable parameters were optimized for the best outputs. The
 186 regression coefficient of the complete second order model and their significance has been
 187 reported (Table 7). High P value indicated that a model had a significant lack of fit and
 188 therefore considered to be inadequate. The lower the value of P, better would be model thus
 189 model having P value lower than 0.1 were accepted.

190 **Table 6: Experiment data for various responses from RSM technique**

Std	Run	Factor X ₁	Factor X ₂	Factor X ₃	Response 1	Response 2	Response 3	Response 4
		Load weight (kilogram)	Height (feet)	Time (minute)	EE (kJ/min.)	RPE (percent)	TCCW (beats)	Grip strength (percent)
1	17	-1	-1	0	10.86	30	676.65	3.22
2	14	1	-1	0	11.35	50	700	7.16
3	6	-1	1	0	10.99	30	536	5.34
4	13	1	1	0	11.65	50	594.04	6
5	15	-1	0	-1	11.63	20	553	5
6	16	1	0	-1	12	45	586.61	5.14
7	2	-1	0	1	11.47	30	796	4
8	7	1	0	1	12.2	40	920.5	6.21
9	1	0	-1	-1	11.81	30	532.84	4.3
10	3	0	1	-1	11.49	45	622.48	6.12
11	10	0	-1	1	11.36	40	746	4.24
12	8	0	1	1	12.96	45	1034.5	7.12
13	9	0	0	0	10.91	40	689.5	5.83
14	5	0	0	0	10.99	45	696	6.45
15	11	0	0	0	11.47	40	715	6
16	12	0	0	0	11.5	45	709	5.57
17	4	0	0	0	10.91	45	689.5	5.6

191

192 **Table 7: Result of regression analysis for responses from RSM technique**

Source	Energy expenditure (kJ/min.)		Rate of perceived exertion (percent)		Total cardiac cost of work (beats)		Grip strength (percent)	
	Coefficient	P value	Coefficient	P value	Coefficient	P value	Coefficient	P value
Model	11.156	0.0172	43	0.0035	699.8	0.0552	5.89	0.0387
X₁	0.28125	0.0276	9.375	0.0001	29.9375	0.3514	0.86875	0.0071
X₂	0.21375	0.0731	2.5	0.0838	16.44125	0.6005	0.7075	0.0183
X₃	0.1325	0.2328	1.875	0.1746	150.25875	0.0015	0.12625	0.6019
X₁, X₂	0.0425	0.7756	0	1.0000	8.6725	0.8438	-0.82	0.0405
X₁, X₃	0.09	0.5503	-3.75	0.0700	22.7225	0.6087	0.5175	0.1574
X₂, X₃	0.48	0.0123	-2.5	0.1973	49.715	0.2794	0.265	0.4442
X_{1,2}	-0.01175	0.9354	-4.625	0.0305	-46.5275	0.2974	-0.40875	0.2403
X_{2,2}	0.06825	0.6404	1.625	0.3738	-26.6	0.5404	-0.05125	0.8767
X_{3,2}	0.68075	0.0018	-4.625	0.0305	60.755	0.1851	-0.39375	0.2564
R²	0.8768		0.9246		0.8194		0.8398	
F Value	5.54		9.54		3.53		4.08	
Lack of fit	NS		NS		S		NS	

193

Effect of independent variables on different responses

194 When a regression model is fitted using two or more continuous predictors, it's useful to
 195 present a graphical visualization of the fitted surface (Lenth, 2012¹⁷) in the form of contour
 196 plot. In a contour plot, two factors at a time can be visualized; the others have to be set to
 197 normally at their central values. Thus by response surface methodology, a complete
 198 realization of the process parameters and their effects were quantified by developing the
 199 contour plot under following heads:

200 **Effect of load weight, height and time on energy expenditure (EE)**

201 Significance of independent variable i.e. load weight, height and time on EE data was tested
 202 using ANOVA (Table 8) and total effect on EE was observed (Table 9). Contour plot Fig. 1
 203 A1 depicting the effect of load weight and height on EE, it was observed that EE was found
 204 to be increased in linear pattern with the both i.e. ramp height and load weight. Fig. 1 A2
 205 shows the effect of load weight and time on EE, it was observed that only time, affects the EE
 206 parameters. Whereas Fig. 1 A3 shows the effect of ramp height and time on EE, it was
 207 observed that only time affects the EE of human.

208 **Table 8: ANOVA for energy expenditure (EE) during experiment**

Source	Df	Sum of square	Mean of square	F Value
Model	9	4.10	0.46	5.54**
Linear	3	1.14	0.38	4.63***
Quadratic	3	0.95	0.31	3.89*
Interactive	3	1.97	0.65	8.01**
Error	7	0.58	0.082	
Total	16	4.64		

209 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9,7) = 6.71; F tab value
 210 (3,7) = 8.45 (1%); (3,7) = 4.34 (5%); F tab value (9, 7) = 2.72; F tab value (3,7) = 3.07 (10%)
 211

212 **Table 9: Total effect of individual parameter on energy expenditure (EE) experiment**

Source	Df	Sum of square	Mean of square	F Value
Model	9	4.10	0.46	5.54**
Load weight (x_1)	4	0.66	0.16	2.04
Height (x_2)	4	1.31	0.32	4.01*
Time (x_3)	4	3.04	0.76	9.27***
Error	7	0.58	0.082	
Total	19	5.59		

213 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9,7) = 6.71; F tab value
 214 (4,7) = 7.84 (1%); F tab value (9, 7) = 3.67 ; F tab value (4,7) = 4.12 (5%); F tab value (9, 7) =2.72; F tab value
 215 (4,7) = 2.96 (10%)
 216

217 **Effect of load weight, height and time on rate of perceived exertion (RPE)**

218 Significance of independent variable i.e. load weight, height and time on RPE data was tested
 219 using ANOVA (Table 10) and total effect on EE was observed (Table 11). Contour plot Fig.
 220 2 A1 depicted the effect of load weight and height on RPE, it was observed that RPE was
 221 found to be increased in linear pattern with the both i.e. ramp height and load weight. From
 222 Fig. 2 A2, which shows the effect of load weight and time on RPE, it was observed that only
 223 load weight affects the RPE parameters. Whereas Fig. 2 A3 shows the effect of ramp height
 224 and time on RPE, it was shows that a minimum region at center which is called as saddle
 225 point and shows that there is no effect of height and time on RPE.

226 **Table 10: ANOVA for rate of perceived exertion (RPE) during experiment**

Source	Df	Sum of square	Mean of square	F Value
Model	9	1057.86	117.54	9.53***
Linear	3	781.24	260.41	21.14***
Quadratic	3	81.25	27.08	2.19
Interactive	3	191.23	63.74	5.17**
Error	7	86.25	12.32	
Total	16	1139.97		

227 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9,7) = 6.71; F tab value
 228 (3,7) = 8.45 (1%); F tab value (9, 7) = 3.67; F tab value (3,7) = 4.34 (5%)
 229 F tab value (9, 7) =2.72; F tab value (3,7) = 3.07 (10%)

230 **Table 11: Total effect of individual parameter on perceived exertion (RPE) experiment**

Source	df	Sum of square	Mean of square	F Value
Model	9	1057.86	117.54	9.53***
Load weight (x_1)	4	849.43	212.35	17.24***
Height (x_2)	4	86.11	21.52	1.75
Time (x_3)	4	199.43	49.85	4.05*
Error	7	86.25	12.32	
Total	19	1221.22		

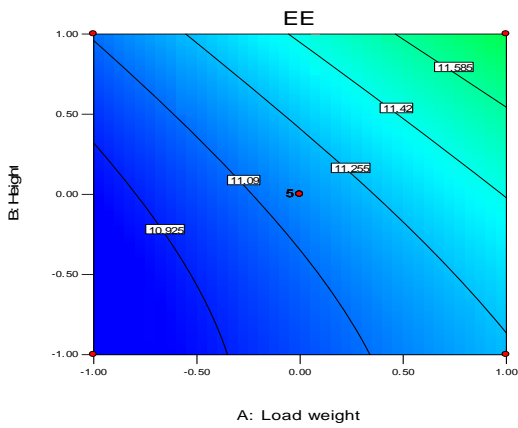
231 ***, **, * significant at 1, 5 and 10 % level of significance respectively tab value (9,7) = 6.71; F tab value (4,7)
 232 = 7.84 (1%); F tab value (9, 7) = 3.67; F tab value (4, 7) = 4.12 (5%); F tab value (9, 7) =2.72; F tab value (4, 7)
 233 = 2.96 (10%)

234 **Effect of load weight, height and time on total cardiac cost of work (TCCW)**

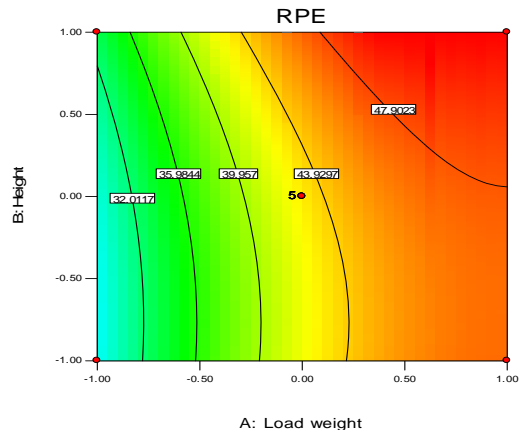
235 Significance of independent variable i.e. load weight, height and time on TCCW data was
 236 tested using ANOVA (Table 12) and total effect on EE was observed (Table 13). Fig. 3 A1 of

237 contour plot depicting the effect of load weight and height on TCCW, it was observed that
238 TCCW was minimum affected by the height of the ramp and only load weight affects the
239 individuals TCCW. Fig. 3 A2 shows the effect of load weight and time on TCCW, it was
240 observed that only time affects the TCCW parameters. Whereas Fig 3 A3 shows a minimum
241 region at centre which is called as saddle point and showed that there is no effect of height
242 and time on TCCW.

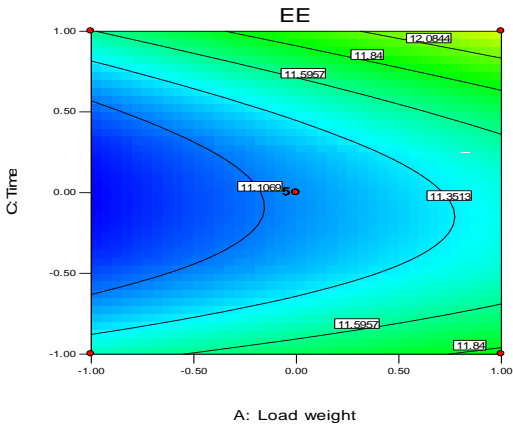
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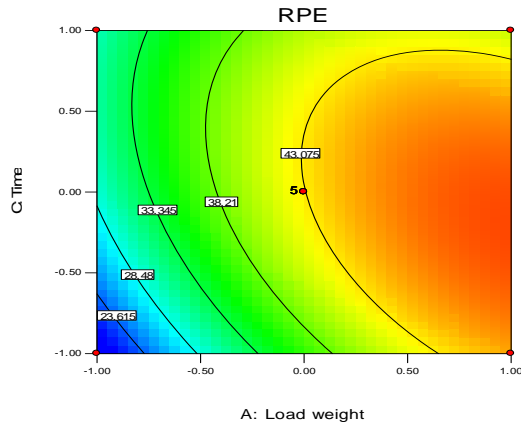
A1: Effect of loadweight and height on EE



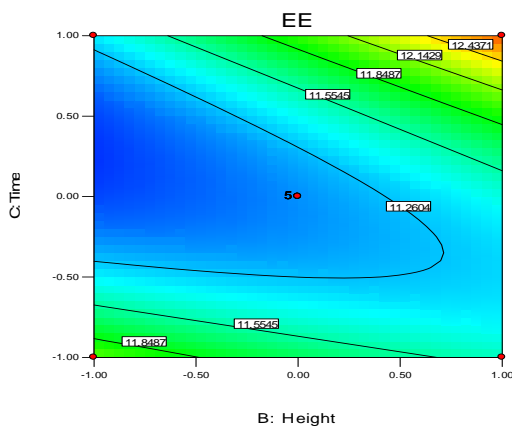
A1: Effect of loadweight and height on RPE



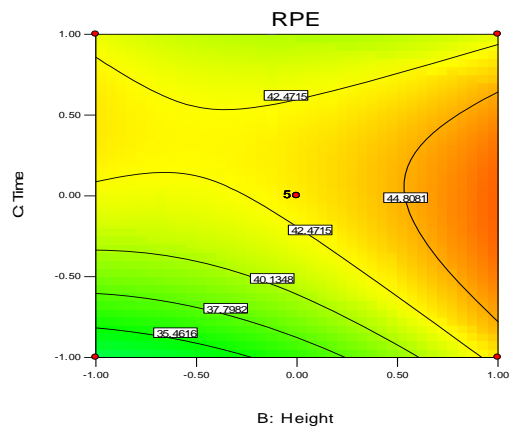
A2: Effect of load weight and time on EE



A2: Effect of load weight and time on RPE



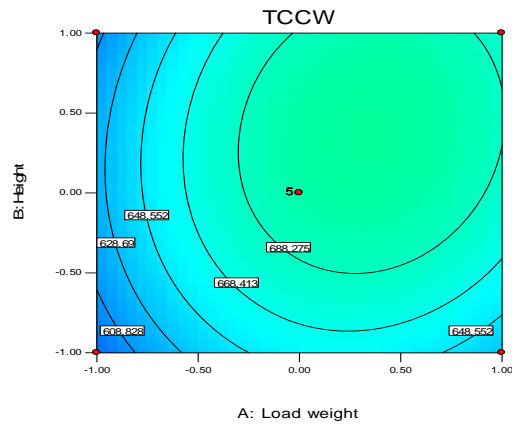
A3: Effect of height and time on EE



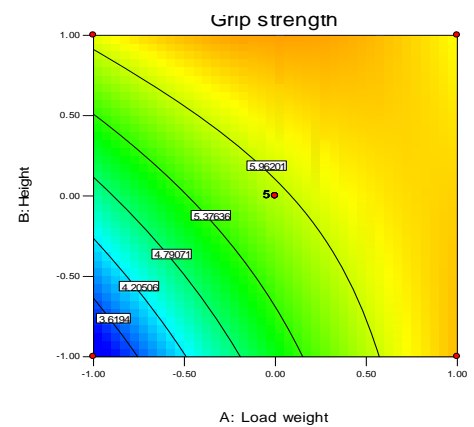
A3: Effect of height and time on RPE

Fig. 1: Contour plots for Energy Expenditure (EE) during experiment

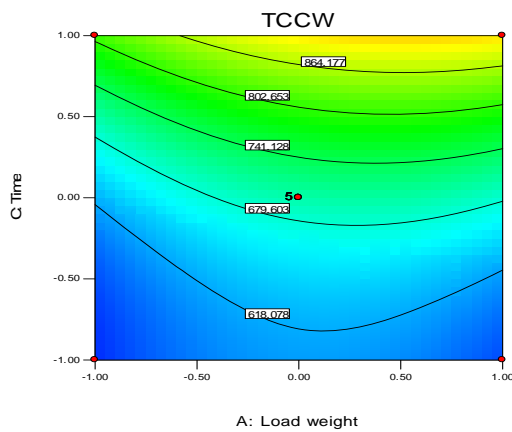
Fig. 2: Contour plots for Rate of Perceived Exertion (RPE) during experiment



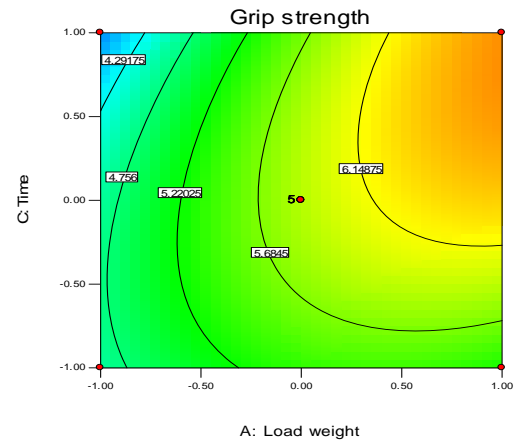
A1: Effect of load weight and height on TCCW



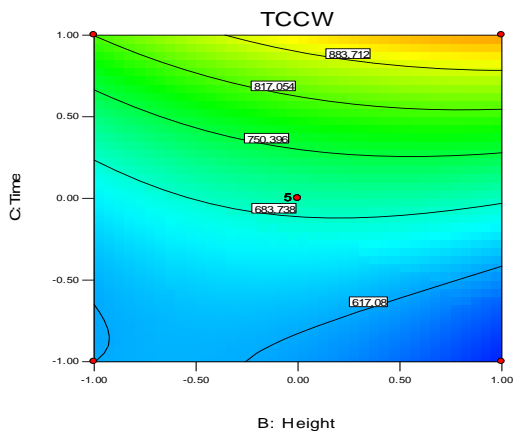
A1: Effect of load weight and height on GS



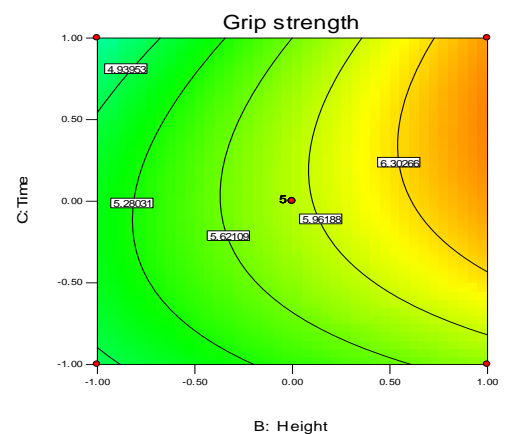
A2: Effect of load weight and time on TCCW



A2: Effect of load weight and time on GS



A3: Effect of height and time on TCCW



A3: Effect of height and time on GS

Fig. 3: Contour plots for total cardiac cost of work (TCCW) during experiment

Fig. 4: Contour plots for grip strength (GS) during experiment

246 **Table 12: ANOVA for total cardiac cost of work (TCCW) during experiment**

Source	df	Sum of square	Mean of square	F Value
Model	9	228496.67	15388.51	3.52
Linear	3	189954.07	63318.02	8.80***
Quadratic	3	12252.4	4084.13	0.57
Interactive	3	27635.74	9211.91	1.28
Error	7	50358.60	7194.08	
Total	16	280200.8		

247 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9, 7) = 6.71; F tab value
 248 (3, 7) = 8.45 (1%); F tab value (9, 7) = 3.67; F tab value (3, 7) = 4.34 (5%); F tab value (9, 7) = 2.72; F tab value
 249 (3, 7) = 3.07 (10%)
 250

251 **Table 13: Total effect of individual parameter on total cardiac cost of work (TCCW)**
 252 **experiment**

Source	df	Sum of square	Mean of square	F Value
Model	9	228496.67	15388.51	3.52
Load weight (x_1)	4	1865	4662.77	0.65
Height (x_2)	4	15328.87	3832.21	0.53
Time (x_3)	4	208114.8	52028.71	7.23***
Error	7	50358.60	7194.08	
Total	19	275667.3		

253 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9,7) = 6.71; F tab value
 254 (4,7) = 7.84 (1%); F tab value (9, 7) = 3.67; F tab value (4,7) = 4.12 (5%); F tab value (9, 7) = 2.72; F tab value
 255 (4,7) = 2.96 (10%)
 256

257 **Effect of load weight, height and time on grip strength (GS)**

258 Significance of independent variable i.e. loads weight, height and time on grip strength data
 259 was tested using ANOVA (Table 14) and total effect of individual parameters was also
 260 observed (Table 15). Contour plot Fig. 4 A1 depicting the effect of load weight and height on
 261 grip strength at centre point and it shows that grip strength was increased with load weight
 262 rather than height. Whereas Fig 4 A2, also showed the effect of load weight and time on grip
 263 strength at centre point and it shows that grip strength was increased with load weight rather
 264 than time. Fig 4 A3 shows the effect of time and ramp height on grip strength, it was
 265 observed that only height affects the grip strength rather than time.

266 **Table 14: ANOVA for grip strength (GS) during experiment**

Source	df	Sum of square	Mean of square	F Value
Model	9	15.68	1.74	4.07**

Linear	3	10.15	3.38	8.05**
Quadratic	3	4.03	1.34	3.20*
Interactive	3	1.36	0.45	1.08
Error	7	2.99	0.42	
Total	16	18.53		

267 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9,7) = 6.71; F tab value
 268 (3,7) = 8.45 (1%); F tab value (9, 7) = 3.67; F tab value (3, 7) = 4.34 (5%); F tab value (9, 7) =2.72; F tab value
 269 (3, 7) = 3.07 (10%)
 270

271 **Table 15: Total effect of individual parameter on grip strength experiment**

Source	df	Sum of square	Mean of square	F Value
Model	9	15.68	1.74	4.07**
Load weight (x_1)	4	10.48	2.62	6.23**
Height (x_2)	4	7.61	1.90	4.52**
Time (x_3)	4	2.12	0.53	1.26
Error	7	2.99	0.42	
Total	19	23.2		

272 ***, **, * significant at 1, 5 and 10 % level of significance respectively; F tab value (9,7) = 6.71; F tab value
 273 (4,7) = 7.84 (1%); F tab value (9, 7) = 3.67; F tab value (4,7) = 4.12 (5%); F tab value (9, 7) =2.72; F tab value
 274 (4,7) = 2.96 (10%)
 275

276 **Optimization of parameters (load weight, height and time) for described responses**

277 Numerical optimization was carried out using design software. The goal was fixed to
 278 minimize heart rate, energy expenditure and musculoskeletal disorder. The responses i.e.
 279 energy expenditure (EE), rate of perceived exertion (RPE), total cardiac cost of work
 280 (TCCW) and grip strength (GS) were taken into consideration for optimization. The goal
 281 seeking begins at a random starting point and proceeds up and down the steepest slope on
 282 the response surface for a maximum and minimum value of the response respectively.
 283 Importance to the responses and independent variables were given on the basis of the
 284 objective of the study. Maximum importance was (+++++) was given to time and EE,
 285 next importance were given to the TCCW (+++++) RPE and GS, while the goal of load
 286 weight and height (++++) was kept at in range similar study was also reported by Rai *et al.*
 287 (2012¹⁸). The goal setup and optimum value of different parameters obtained is given in
 288 Table 16.

289

290

291 **Table 16: Constraints for optimization of parameters**

Name	Goal	Lower Limit	Upper limit	Goal setting
Load weight	in range	-1	1	+++
Ramp height	in range	-1	1	+++
Time	minimum	-1	1	+++++
Energy expenditure (EE)	minimum	-1	1	+++++
Rate of perceived exertion (RPE)	minimum	-1	1	++++
Total cardiac cost of work (TCCW)	minimum	-1	1	++++
Grip strength (GS)	minimum	-1	1	++++

292 **Table 17: Optimum values of parameters for experimentation of loading ramp**

Value	Load weight (kg.)	Height (feet)	Time (minutes)	EE (kJ/min.)	RPE (%)	TCCW (beats)	Grip strength (%)	Desirability
Coded	-1	-1	-0.71					
Actual	40	3	3.29	11.41	20.00	564.36	3.30	0.84

293 During optimization 17 solution were obtained, out of which the most suitable criteria, was
 294 selected. The selected solution was tested for the actual conditions and it was observed out of
 295 three independent variable optimum results were obtained when the load weight 40 kg.,
 296 height 3 feet and time 3.29 minute (Table 17) which shows the reduction of energy
 297 expenditure from 14.55 kJ/min. to 11.41 kJ/min., RPE from 85.45 to 20 %, TCCW from
 298 996.3 to 564.36 beats and GS from 47.45 to 3.30 % with overall desirability of 0.84 %.
 299 Hence, this combination shows the maximum efficiency with minimum time, energy,
 300 TCCW and grip strength by working with loading ramp. Similarly Pandey and Vinay
 301 (2016¹⁹) in a study of RSM on use of pant loading ramp reported that it was able to reduce
 302 heart rate of selected respondent's from 135.4 beats/min. to 126.76 beats/min., MSD from
 303 85.45 to 22.80 % and VO2 max from 39.45 to 34L/min. Similarly Aruna and Dhanalaksmi
 304 (2012²⁰) optimized the surface roughness when turning Inconel 718 with cermet inserts by
 305 using response Surface Method (RSM). Optimized machining parameters are validated
 306 experimentally, and it is observed that the response values are in reasonable agreement with
 307 the predicted values. Kumar *et al.* (2013²¹) used RSM to determine the optimum machining
 308 parameters leading to minimum surface roughness and maximum metal removal rate in
 309 Surface grinding process.

310 **Comparative performance of the pant loading ramp and existing wooden plank.**

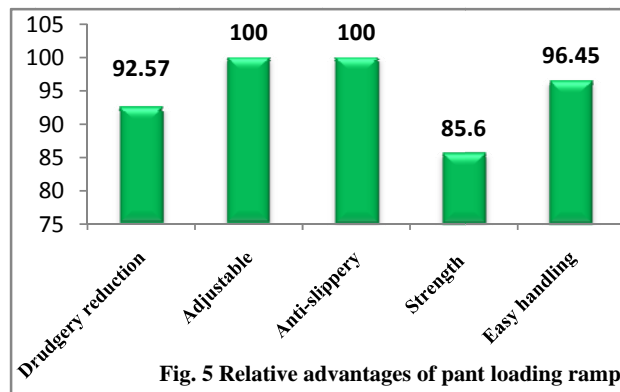
311 Use of developed loading ramp was able to reduce average energy expenditure of selected
 312 respondents from 14.55±3.12 to 11.41±1.10 kJ/min., peak energy expenditure from
 313 16±1.36 to 12±0.32 kJ/min., rate of perceived exertion from 85.45±8.43 to 20±2.1 %, grip
 314 strength from 47.45±2.14 to 3.30±0.27 % and TCCW from 996.3±5.45 to
 315 564.36±3.41beats. It means the energetic workload and perceived discomfort of the
 316 respondents in different body regions differ significantly for the use of both traditional
 317 and developed loading ramp.

318 **Table 18: Comparative evaluation of pant loading ramp and existing wooden plank**

S. No.	Physiological parameters	Wooden plank (Mean±SD)	Pant Loading ramp (Mean±SD)
1	Average Energy Expenditure (AWHR) (kJ/min)	14.55±3.12	11.41±1.10
2	Peak Energy Expenditure (PEE) (kJ/min.)	16±1.36	12±0.32
3	Rate of Perceived Exertion (RPE) (%)	85.45±8.43	20±2.1
4	Grip Strength (GS) (%)	47.45±2.14	3.30±0.27
5	Total cardiac cost of work (TCCW) (Beats)	996.3±5.45	564.36±3.41

319 **Relative advantage regarding pant loading ramp**

320 Relative advantages of pant
 321 loading ramp was evaluated on the
 322 basis of five parameter and the figure
 323 below depicted that 92.57 %
 324 respondents were satisfied with the
 325 drudgery reduction concept of ramp and
 326 all the respondents were believed that
 327 the improved loading ramp was
 328 adjustable and anti-slippery. While, 85.6 % workers were satisfied that the strength of
 329 loading ramp was good. Furthermore 96.45 % respondents revealed that ramp was very easy
 330 to handle from one place to another because of light weight and provision of rotating wheel.



331 **CONCLUSION**

332 In conclusion it was observed that use of pant loading ramp was able to reduce
 333 Energy Expenditure (EE) of respondents' from 14.55 kJ/min. to 11.41 kJ/min., Rate of

334 Perceived Exertion (RPE) from 85.45 to 20 %, Total Cardiac Cost of Work (TCCW) from
335 996.3 to 564.36 beats and Grip Strength (GS) from 47.45 to 3.30 % with overall
336 desirability of 0.84 %. Hence, this combination shows the maximum efficiency with
337 minimum time, energy and psychophysical discomfort was obtained by loading ramp. In
338 comparison with traditional method it was also found to reduce Average Working heart
339 Rate (AWHR) (14.55-11.41), Peak Energy Expenditure (PEE) (16-12), Rate of Perceived
340 Exertion (RPE) (85.45-20), Grip Strength (GS) (47.45-3.30) and Total Cardiac Cost of
341 Work (TCCW) (996.3-564.35). Relative advantages showed that more than 95 % users were
342 highly satisfied and found it advantageous.

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