Optimization of Human Comfort Reaction for Suspended Cabin Tractor Semitrailer Drivers

L.A.Kumaraswamidhas, P.Velmurugan, K.Sankaranarayanasamy

Abstract**—**This work has been conducted to study on comfort level of drivers of suspended cabin tractor semitrailer. Some drivers suffer from low back pain caused by vibration. The practical significance of applying suspended cabin type of tractor semi trailer was tested at different road conditions, different speed as well as different load conditions for comfortable driver seat interface (x, y, z) and the process parameters have been prioritized using Taguchi's L27 orthogonal array. Genetic Algorithm (GA) is used to optimize the human comfort vibration of suspended cabin tractor semitrailer drivers. The practical significance of applying GA to human comfort to reaction of suspended cabin tractor semitrailer has been validated by means of computing the deviation between predicted and experimentally obtained human comfort to vibration. The optimized acceleration data indicate a little uncomfortable ride for suspended cabin tractor semitrailer.

Keywords**—**Genetic Algorithm, Ride Comfort, Taguchi Method, Tractor Semitrailer

I. INTRODUCTION

RIDE comfort is generally used to describe the degree of human comfort offered by a moving vehicle. The international standard of ISO-2631 [1] defines the ways to assess the ride comfort in an objective manner by evaluating vibration and gives the definition of ride comfort index. This standard was applied to the evaluation of ride comfort regarding the tractor semi trailer vehicles used in Indian road ways. The ISO 2631 provides three methods of measurement and its corresponding calculation was used for evaluating ride comfort using two methods for seating position and standing position respectively; a simplified method was used for seating position. The simplified method for seating position was adopted in tractor semi trailer. Literature reviews have shown that the off-road vehicle operators were exposed to high levels of human comfort vibrations [2], several types of low back symptoms among the bus drivers employed at a public transport company were investigated [3], the translational produced greater discomfort than the rotational in which roll and pitch caused increasing discomfort over yaw vibrations with the most predominant discomfort in Z- [4], it might be adequate to measure the total vibration discomfort by the dominant axes in some conditions with combined translational and rotational environments [5], and operators are subjected through seat operator interface which suggests that there is no improvement of skidder seat vibration attenuation [6]. These off-road vehicles show pitch being the predominant axes of chassis rotational acceleration whereas roll was found to be the predominant axes in the current investigation. Nonetheless, values determined by [7] are substantially smaller than those presented in this paper. Higher accelerations were also reported in load haul dump trucks [8] in the X- when compared to those reported in this paper for forestry skidders.Indian tractor semi trailer drivers are exposed to human comfort during their work and some drivers suffer from low back pain due to their work environment. A brief specification of the tractor semitrailer employed for the testing is given in table I. In the present study, the input parameters considered are road roughness (paved road, Asphalt Road, smooth road), speed (40, 50,60km per hour), load conditions (7, 25, 49 tons), and the output parameter is driver seat accelerations. Taguchi L27 orthogonal array has been used and the most significant process parameter has been identified. This is followed by the conduct of ANOVA for ensuring the statistical significance of the process parameters. Then non-traditional optimization technique namely Genetic Algorithm has been used to derive the optimized process parameters of the human comfort to vibration for suspended cabin tractor semitrailer.

TABLE I
SPECIFICATION OF TRACTOR SEMITRAILER

Specification	Tractor semitrailer
Wheel base (m)	3.850
Type of engine	Diesel
Tractor suspension features front side	Multiple Leaf spring
Tractor suspension features rear side	Multiple Leaf spring
Semitrailer suspension features rear side	Multiple Leaf spring
Axle	3 axles (tractor), 3 axles (semitrailer)
Unladen (kg)	7000
Laden (kg)	49000
Cabin feature	suspended cabin

II. HUMAN COMFORT MEASUREMENT

The vibration total value is obtained from the square root of the sum of the squares of the measured (r.m.s) ISO -weighted acceleration values in the x, y, and z directions.

The vibration total value (A_{WT}) was calculated for the vector sum of the translational as outlined by ISO 2631-1:1997 as

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$$A_{WT} = \sqrt{(w_d a_x)^2 + (w_d a_y)^2 + (w_d a_z)^2} \quad (1)$$

Where 'a' is the weighted acceleration in the respective axes and w is the multiplying factor. When quantifying the vibration total value (A_{WT}) for health effects, w_d = 1 for X- , Y- and Z-axes. Root-mean-square vibration magnitudes were calculated from the frequency-weighted acceleration time histories. The weightings and multiplying factors in equation (1) are those defined in ISO 2631 for evaluating vibration with respect to human comfort. Five levels of ride comfort index are defined in the ISO 2631 to describe the comfort perception, as listed in the table II. The calculated vibration total values were then compared to the comfort reaction of the ISO 2631-1:1997[1].

TABLE II
RIDE COMFORT EVALUATION

Vibration Total Valve A_{wt} (m/s^2)	Comfort level
Less than 0.315 m/s^2	Not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	A little uncomfortable
0.5 m/s^2 to 1.0 m/s^2	Fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	uncomfortable
1.25 m/s^2 to 2.5 m/s^2	Very uncomfortable
Greater than 2 m/s^2	Extremely uncomfortable

III. Experimental Procedure

The configuration of the tractor semitrailer was successfully tested to measure the human comfort reaction to vibration environment. Fig.1 depicts the representation of tractor semitrailer.

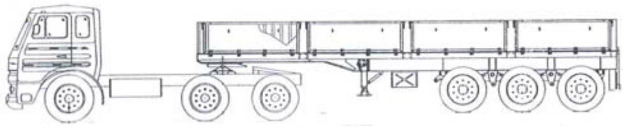

Fig. 1 Tractor semitrailer

The suspended cabin consists of spring and damper between the chassis and cabin. Fig. 2 illustrates the suspended cabin. The measurement of the human comfort vibration of tractor semitrailer under different condition is shown in table III. The vibration total value for the different measurement conditions of the tractor semitrailer was measured at the driver/seat interface (x, y and z axes) (ISO 2631/1, 1997). Tri-axial vibration values on the driver seat were measured by piezoelectric accelerometers Bruel & Kjaer type 4322 in Fig. 3. The three recorded acceleration signals for each of the conditions of table III were acquired on a digital computer for 180 seconds at 1024 samples per second using 167 Hz anti-aliasing filters. Frequency weighted accelerations were calculated by using the weighting factors suggested by ISO 2631-1.Only one driver participated in this study. The driver was 44 years old, 170 cm tall and weighed 79 kg. He had approximately 20 years of experience in driving tractor semitrailers.

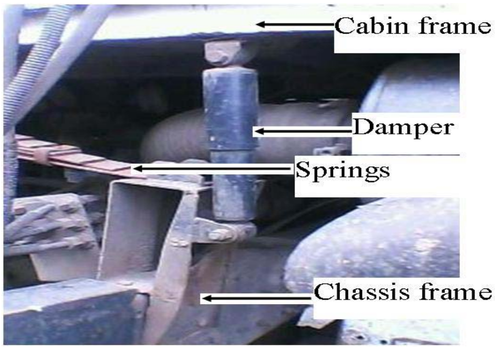

Fig. 2 Suspended cabin

Fig. 3 Measurement location on Seat pad accelerometer

The vibration total values were measured at the driver seat interface by using a triaxel seat pad accelerometer (B&K type 4322). The vibration measurements were carried out performed by using a Cronos-PL/SL/compact Version 3.1 field computer system.

IV. Results and Discussion

To quantify the comfort reaction to vibration in tractor semitrailer the weighted acceleration monitored from driver seat interface are recorded for various combinations of test conditions which are listed in table III. The measurements were analyzed according to the recommendations in the human comfort and compared with the comfort reaction to vibration environment which was given in ISO 2631-1 standard. From the vibration acceleration values measured on x, y and z , the overall vibration total values are computed using the equation (1). In this study, road conditions (smooth road, asphalt road, paved road), different speed (40, 50, 60 km/h) as well as different load condition (7, 25, 49 ton) were considered for comfort reaction to vibration assessment in the tractor semi trailer. From the vibration acceleration values measured above x, y and z, overall vibration total values are computed in equation (1). Taguchi L27 orthogonal array has been used and the most significant process parameter has been identified. Then non-traditional optimization technique namely Genetic Algorithm has been used to derive the optimized process parameters of the suspended cabin tractor semitrailer.

A. Taguchi method

Taguchi method is an efficient tool which enables the up gradation of the performance of the product, process, and design with significant prediction of cost and time [9- 11]. It is a systematic approach for enabling the design optimization thereby ensuring both quality and performance by means of Taguchi parameter design concept. The system performance could be optimized by means of systematic setting of design parameter and reducing the fluctuations.Taguchi method employs a special design of orthogonal arrays to study entire process parameters space with small number of experiments. The optimal result could be generated out of Taguchi method by means of systematic analysis of data and the dominant factor involved in optimization. In this study, L_{27} orthogonal array has been used and three process parameters considered in this study; Road roughness (m^{-1}), Load conditions (Tons) and Speed (km/h).The factors and their corresponding values are presented in table IV. The format of L_{27} orthogonal array is presented in table V. Table VI shows the various input parameters and output parameters of human comfort vibration of suspended cabin tractor semi trailer. The ranking of process parameters generated by the conduct of Taguchi method is shown in table VII. As inferred from table VII, Road roughness has been ranked as the first process parameter followed by the Speed and Load conditions.

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TABLE III
WEIGHTED ACCELERATION LEVELS FOR TRACTOR SEMITRAILER

	Inputs			Outputs			
Exp. No	Road (m^{-1})	Load (Tons)	Speed (km/h)	X- (m/s^2)	Y- (m/s^2)	Z- (m/s^2)	A_{WT} (m/s^2)
1	smooth road	low load	40	0.2239	0.1407	0.6285	0.6819
2	smooth road	low load	50	0.2855	0.1762	0.7034	0.7793
3	smooth road	low load	60	0.3452	0.2206	0.7824	0.8832
4	smooth road	medium load	40	0.2001	0.1438	0.6128	0.6607
5	smooth road	medium load	50	0.2451	0.1706	0.6986	0.7606
6	smooth road	medium load	60	0.3081	0.2213	0.7637	0.8532
7	smooth road	high load	40	0.1763	0.1468	0.597	0.6396
8	smooth road	high load	50	0.2047	0.1649	0.6938	0.7419
9	smooth road	high load	60	0.271	0.222	0.745	0.8233
10	Asphalt Road	low load	40	0.3065	0.2307	0.8222	0.9080
11	Asphalt Road	low load	50	0.3433	0.2611	0.9172	1.0140
12	Asphalt Road	low load	60	0.3836	0.2929	0.9942	1.1060
13	Asphalt Road	medium load	40	0.3000	0.2411	0.7916	0.8822
14	Asphalt Road	medium load	50	0.3361	0.2699	0.8761	0.9789
15	Asphalt Road	medium load	60	0.3827	0.3052	0.9638	1.0820
16	Asphalt Road	high load	40	0.2936	0.2515	0.7611	0.8564
17	Asphalt Road	high load	50	0.3288	0.2787	0.8350	0.9437
18	Asphalt Road	high load	60	0.3819	0.3174	0.9335	1.0581
19	Paved Road	low load	40	0.3891	0.3207	1.0158	1.1341
20	Paved Road	low load	50	0.4011	0.3459	1.1309	1.2488
21	Paved Road	low load	60	0.4219	0.3652	1.2059	1.3287
22	Paved Road	medium load	40	0.4000	0.3385	0.9705	1.1036
23	Paved Road	medium load	50	0.4270	0.3692	1.0536	1.1971
24	Paved Road	medium load	60	0.4573	0.3890	1.1639	1.3109
25	Paved Road	high load	40	0.4108	0.3562	0.9252	1.0731
26	Paved Road	high load	50	0.4529	0.3924	0.9762	1.1455
27	Paved Road	high load	60	0.4927	0.4128	1.1219	1.2930

B. Analysis of variance (ANOVA)

The statistical analysis of variance (ANOVA) has been performed to predict the statistical significance of the process parameters [12]. It helps to determine the effect of individual input parameter on output parameters. The results of ANOVA are presented in table VIII.

TABLE IV
FACTORS AND LEVELS

Factors	Levels		
	1	2	3
Road roughness(m^{-1})	0.15	0.3	0.45
Load conditions (Tons)	7	25	49
Speed (km/h)	40	50	60

Based on the results presented in table VIII, Road roughness is found to be the most influencing parameter with 81.99 % contribution followed by Speed (16.49 %) and Load conditions (1.32 %) and is shown in Fig. 4. The main effects plot generated by MINITAB software pertaining to ANOVA is shown in Fig. 5 [13]. It can be inferred that lower human comfort vibration could be obtained when the speed and Road roughness are low and Load conditions is large. However at very high speeds and rough road condition, human comfort vibration acceleration is high.Genetic Algorithm (GA) is a nontraditional optimization algorithm based on the principles of natural genetics. The principle of natural genetics is that 'Fit parents would yield fit offspring'. GA has wide variety of application in engineering problems because of simplicity and ease of operation [14].The minimum or maximum of a function is found based on the variation of X_1, X_2, X_3 …… X_n beginning with one or more starting point. GA evaluates a set of points, and the basic elements of GA consist of a chromosome and fitness value. The fitness value describes how well an individual can adapt to survival and mating. In our study, the basic elements of GA consist of a value of road roughness, speed, load conditions and human comfort vibration= f (RR, S, LC). = f (S, PC, SD). GA works on the basis of binary code in the form of 0 and 1. An individual in GA is denoted by I={ RR, S, LC, f (RR, S, LC)}. A set of search individual is called a population and general structure of GA is shown in Fig.6 and convergence GA result depicting in Fig. 7.The parameters used in GA are; population size=100, length of chromosome=20, selection operator=stochastic uniform, crossover probability=0.8, mutation probability=0.2, fitness parameter = Acceleration. The objective function is given by acceleration = f (RR, S, LC).

Human comfort vibration input parameter constraint

The practical constraints imposed during human comfort vibration analysis process are stated as follows:

Parameter bounds:

Bounds on road roughness (RR)

$RR_L \leq RR \leq RR_H$

Where RR_L = 0.15 RR_H = 0.45 are least and highest road roughness respectively.

Bounds on speed (S)

$S_L \leq S \leq S_H$

Where S_L = 40 S_H = 60 are least and highest speed respectively.

Bounds on load conditions (LC)

$LC_L \leq LC \leq LC_H$

Where LC_L = 7 LC_H = 49 are least and highest load condition respectively.

C. Optimization by Genetic Algorithm

Table IX presents the optimized parameters for obtaining Minimum acceleration. Based on the optimum value, validation experiment has been conducted using the feasible input parameters. There has been a narrow deviation between the theoretically predicted and experimentally obtained values for driver seat acceleration which conform the practical applicability of GA to suspended cabin driver seat vibration process. Hence a minimum acceleration levels has been achieved by the optimization study.

TABLE V
EXPERIMENT LAYOUT USING L27 ORTHOGONAL ARRAY

Exp. No	Suspended cabin tractor semitrailer parameters level		
	(Road roughness)	(Load conditions)	(Speed)
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

TABLE VI
INPUT PARAMETERS OF ORTHOGONAL ARRAY AND THE OUTPUT CHARACTERISTICS

Exp. No	Input parameters			Output characteristics
	Road roughness (1/m)	Load conditions (Tons)	Speed (km/h)	A_{wt} (m/s^2)
1	0.15	7	40	0.6819
2	0.15	7	50	0.7793
3	0.15	7	60	0.8832
4	0.15	25	40	0.6607
5	0.15	25	50	0.7606
6	0.15	25	60	0.8532
7	0.15	49	40	0.6396
8	0.15	49	50	0.7419
9	0.15	49	60	0.8233
10	0.3	7	40	0.9080
11	0.3	7	50	1.0140
12	0.3	7	60	1.1060
13	0.3	25	40	0.8822
14	0.3	25	50	0.9789
15	0.3	25	60	1.0820
16	0.3	49	40	0.8564
17	0.3	49	50	0.9437
18	0.3	49	60	1.0581
19	0.45	7	40	1.1341
20	0.45	7	50	1.2488
21	0.45	7	60	1.3287
22	0.45	25	40	1.1036
23	0.45	25	50	1.1971
24	0.45	25	60	1.3109
25	0.45	49	40	1.0731
26	0.45	49	50	1.1455
27	0.45	49	60	1.2930

TABLE VII
RANKING OF MOST INFLUENCE PARAMETERS BY TAGUCHI'S METHOD

Level	Road roughness (m^{-1})	Load conditions (Tons)	Speed (km/h)
1	0.75819	1.00933	0.88218
2	0.98103	0.98102	0.97887
3	1.20387	0.95273	1.08204
Delta	0.44568	0.05660	0.19987
Rank	1	3	2

V. CONCLUSIONS

In this study, human comfort vibration analysis for suspended cabin tractor semitrailer process has been used to driver seat vibration on seat cushion. This process is capable of reducing the human comfort vibration of suspended cabin tractor semitrailer drivers.

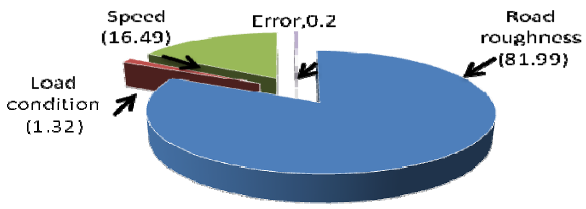

Fig. 4 Contribution in percentage of human comfort vibration analysis of suspended cabin tractor semitrailer process parameters

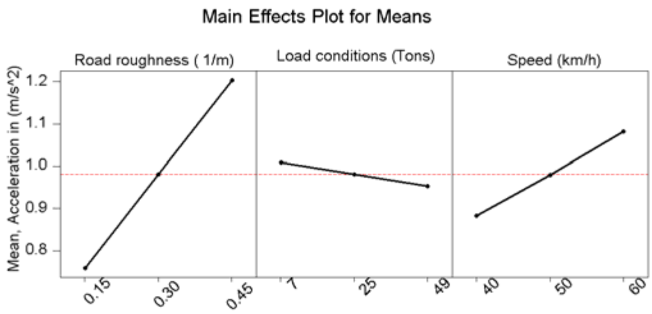

Fig. 5 Main effects plot generated by MINITAB software

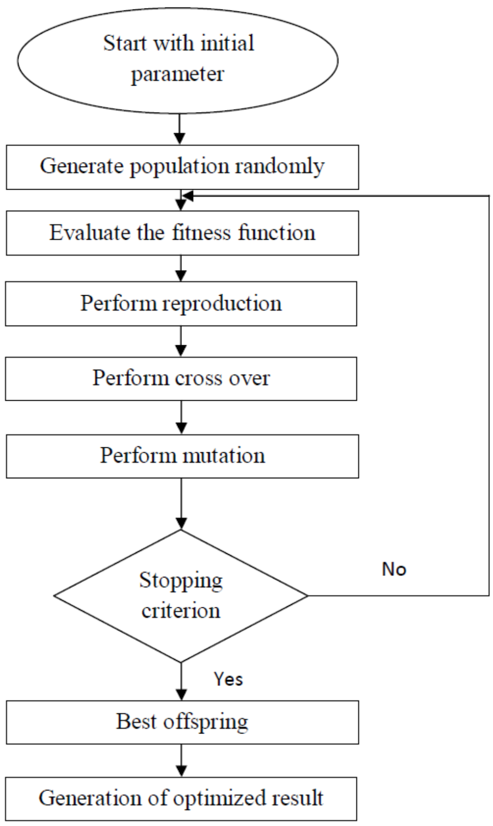

Fig. 6 General structure of genetic algorithm

TABLE VIII
ANALYSIS OF VARIANCE FOR HUMAN COMFORT VIBRATION, USING ADJUSTED SS FOR TESTS

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage of contribution
Road roughness(m^{-1})	2	0.89383	0.89383	0.44691	4243.34	0.000	81.99
Load conditions (Tons)	2	0.01442	0.01442	0.00721	68.44	0.000	1.32
Speed (km/h)	2	0.17982	0.17982	0.08991	853.69	0.000	16.49
Error	20	0.00211	0.00211	0.00011			0.20
Total	26	1.09017					100

DF = degree of freedom, Seq SS = Sequential sum of square, Adj SS = Adjusted sum of square, Adj MS= Adjusted Mean square, F= statistical test, P= Statistical value

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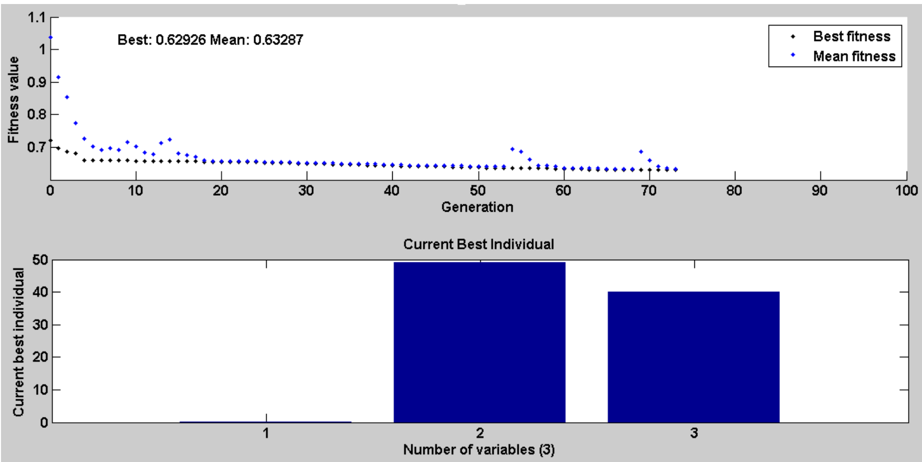

Fig. 7 Screenshot depicting the convergence result obtained using GA

TABLE IX
OPTIMIZED RESULTS

	Road roughness (m^{-1})	Load condition (Tons)	Speed km/h)	Acceleration (m/s^2)
GA	0.15	48.999	40.001	0.62926
Experiment value	0.15	49	40	0.6396

Also, this process is capable of reducing the driver seat vibration with enhanced driver comfort improvement with lesser driver fatigue. Taguchi L27 orthogonal array has been used in this study and the statistical significance of the cabin acceleration parameters has been determined by the conduct of ANOVA. Percentage contributions of the parameters have been found and the road roughness possess highest contribution (83 %) followed by the speeds (16.085 %) and the load conditions (0.764 %). The optimization of the process parameters has been carried out using GA. The optimized value of road roughness, speed, load conditions and driver seat acceleration are 0.15 m^{-1}, 40 kmph, 49 ton and 0.6396 m/s^2 respectively. The optimized acceleration data indicate a little uncomfortable ride for suspended cabin tractor semitrailer. The coherence between the theoretically optimized values and the experimentally obtained values of the process parameters ensures the high potential of applying GA to the human comfort vibration for suspended cabin tractor semitrailers.

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