# An approach to Analysis of Noise and Vibration of Automobile by Using DOE-TOPSIS Method

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## ABSTRACT

When elastic body such as a spring, a beam and shaft are displaced from the equilibrium position by the application of external forces and then released, they execute a vibratory motion. This paper focus on literature review of an automobile noise and vibration propose a heuristic approach to analyze noise and vibration of an automobile. For the measurement of vibration of car *FFT Analyzer* is used. Analysis is to be done by using *MINITAB* software and *DOE-TOPSIS* method.
This paper helps to find out the best set of input parameter or most favorable value of different parameter which are the main source of vibration in automobile interior.

**Key words:** FFT Analyzer, vibration, automobile, MINITAB, DOE-TOPSIS.

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## INTRODUCTION

The vehicle vibration is an unwanted effect. It causes many difficulties i.e. increase in fuel consumption, damage to element of vehicle etc. vibration is a major source of noise disturbance for people for comfort and safety driving. It is very important to know what kind and values of vibration transfer from the different component of an automobile (car) to its cabin [1].
Since last four decades a huge study has been carried out by researchers in automobile field to find out the solution of passenger car cabin vibration as well as noise. To improve the driving quality level of vibration and noise should be minimum. Generally noise is generated by different vehicle system. Vibration in car interior affects driver emotion and reduces the concentration of the driver. Also vibration is a main cause of reduction in

driving comfort, which directly affect the focus of the driving and it may leads to sever accident [2].

In the recent year a demand for comfortable and quite automobile (car) has encouraged the automobile industrial development of different methods to accommodate a balance of comfort, efficiency and performance in new car. Mainly the NVH characteristic of car becoming increasingly important [3].

## EVALUATION OF NOISE AND VIBRATION

Based on previous study a number of sources of noise have been identified. The main source of vehicle interior noise is engine transmission during change in velocity i.e. (positive and negative) of the car. The vibration of the dash board and different parts of vehicle create a noise. Gear box, clutch, transmissions are the major contributor of interior noise.
Generally vibration is directly related to engine seed. The vibration in vehicle interior can be classified in to two groups' combustion vibration and mechanical vibration [4].

## PROPOSED METHODOLOGY

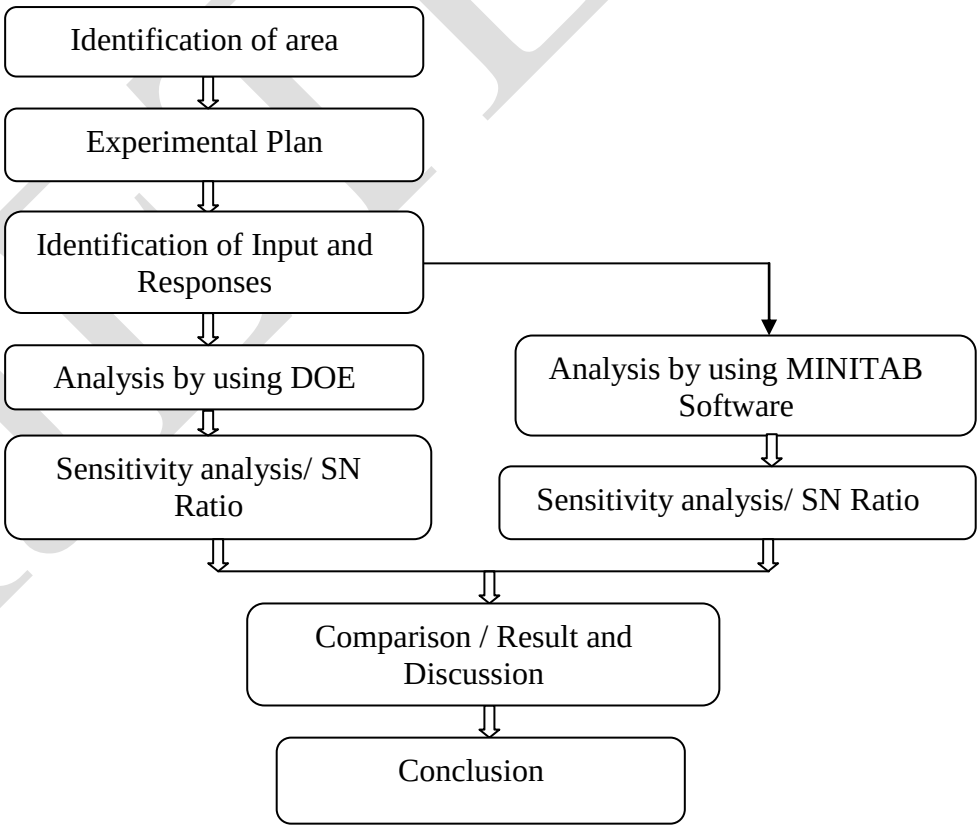



Fig 1: Proposed Methodology.

## EXPERIMENTAL PLAN

In this present paper it is decided to select a one car which is SWIFT VDI. For this car different parameter is selected. The two level of each parameter is selected. By setting different level of selected parameter subsequent noise and vibration measurement is carried out with the help of FFT Analyzer. For each reading time (t) is kept constant and it is 30 sec. in this way for every 8 cases value of responses is recorded. Further analysis is done by using DOE analytical method. The result obtained from DOE method is compared with the result of MINI TAB16 software. From this analysis contribution of each parameter is find out.

### Identification of Input and Output:

Following are the significant input sources of vibration in a vehicle body. Two level of each parameter is selected.

Table1. Input parameter / Sources of Vibration with its Specified Level.

| Sr. No | Parameter | Level - | Level + |
|---|---|---|---|
| **P1** | **Engine Bonnet** | 5 to 6 mm open | Fully closed |
| **P2** | **Vehicle pay load** | Fully loaded (3 per.+1 Driver) | Partially loaded (1 per. +1 Driver) |
| **P3** | **Road Profile** | Smooth | Rough |
| **P4** | **Seat** | Cushion | Normal |
| **P5** | **Air in front wheel** | Normal | Less |
| **P6** | **Air in rear wheel** | Normal | Less |
| **P7** | **Door sealing** | Half open | Fully closed |

### Out-put / Response:

Responses are measured in terms of SPL for noise and frequency, displacement, velocity, and acceleration for vibration.

**1)** Sound Pressure level (SPL) in DB (Y1).
**2)** Vibration (Y2)
- 2.1 Frequency (Y21)
- 2.2 Displacement (Y22)
- 2.3 Velocity (Y23)
- 2.4 Acceleration (Y24)

While conducting experiment following are the possible running condition of vehicle. By achieving these condition noise and vibration measurement is carried out as explained in the experimental plan.

Table2. Different Conditions for Experiment; For CAR I, II, and III

| Case no: | Condition |
|---|---|
| 1 | Idle |
| 2 | **Stationary reverse up (WOT) i.e. stationary accelerate min to maximum** |
| 3 | In first gear |
| 4 | In second gear |
| 5 | In third gear |
| 6 | In fourth gear |
| 7 | In fifth gear |
| 8 | In reverse gear |

For selected model of a car and for different condition /cases observation table is given as follows.

Table3. Observation Table for the car I & Condition I (Idle)

| Run | Parameters | | | | | | | Car I/ condition I (Idle) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 | P7 | Y1 | Y21 | Y22 | Y23 | Y24 |
| 1 | - | - | - | - | - | - | - | | | | | |
| 2 | - | - | + | + | + | - | + | | | | | |
| 3 | - | + | - | + | - | + | + | | | | | |
| 4 | - | + | + | - | + | + | - | | | | | |
| 5 | + | - | - | - | + | + | + | | | | | |
| 6 | + | - | + | + | - | + | - | | | | | |
| 7 | + | + | - | + | + | - | - | | | | | |
| 8 | + | + | + | - | - | - | + | | | | | |

## Analyses by Using DOE Method:

Explanation of the applied DOE- Method.
The applied Taguchi-Method deducts from a full- factorial matrix. With such a matrix all possible combinations have to be determined. The benefit of this method is that the response of all parameters as well as the response of the interactions between the parameters could be evaluated. In table 1 a full factorial matrix for the three parameters is shown. The parameters are varied only between the two values “a” and “b” .According to the given equation, eight tests are necessary.

$$N = n^{k} \text{---------- (Eqn. 1)}$$

Where
N= Number of Tests
n = number of alternating steps (Levels)
k = Number of parameters.

There are 18 orthogonal arrays table in the Taguchi catalogue, these being denoted by $L_N$ ($S^k$) or just by $L_N$. Here $L_N$ ($S^k$) is a matrix with dimensions N x k, S distinct elements and the property that every pair of columns contains all possible $S^2$ ordered pairs of elements with the same frequency. In particular, N is the number of rows and k is the number of columns in the orthogonal arrays. Elements of an orthogonal array can be numbers, symbols or letters. As only 2- elements orthogonal arrays is discussed here, in the orthogonal arrays $L_N(s^k)$ considered here.

$N=2^r$ : Number of rows; r= 2, 3, 4, --------.
S=2 : Number of distinct element
K=N-1 : Number of Columns

After collecting data L8 Taguchi full factorial Matrix for the analysis is prepared. As shown in following table.

Table4. L8 Taguchi full factorial Matrix

| Run | Parameters | | | | | | | RESPONSE |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 | P7 | |
| 1 | - | - | - | - | - | - | - | Y1 |
| 2 | - | - | + | + | + | - | + | Y2 |
| 3 | - | + | - | + | - | + | + | Y3 |
| 4 | - | + | + | - | + | + | - | Y4 |
| 5 | + | - | - | - | + | + | + | Y5 |
| 6 | + | - | + | + | - | + | - | Y6 |
| 7 | + | + | - | + | + | - | - | Y7 |
| 8 | + | + | + | - | - | - | + | Y8 |

## Post Processing Calculation of Design of Experiment (DOE) Method

From the analytical data available in L8 Taguchi full factorial Matrix further analysis is done.

**Ideal Condition:**

Table5. Case I Noise and Vibration.

| Run | Parameters | | | | | | | Car I/Condition I (Response) Ideal | |
|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P4 | P5 | P6 | P7 | Y1 Noise | Y2Vibration |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 54.46 | 1.23 |
| 2 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 54.09 | 1.58 |
| 3 | 1 | 2 | 1 | 2 | 1 | 2 | 2 | 57.25 | 1.63 |
| 4 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 57.35 | 1.78 |
| 5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 57.93 | 1.63 |
| 6 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 58.36 | 1.55 |
| 7 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 54.77 | 1.88 |
| 8 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 53.88 | 1.92 |

## Analysis of Means (ANOM)

The overall mean value of response 'Y' for the experimental region defined by the parameters levels in table is given by

$$m = \frac{1}{8}\sum_{i=1}^{8} Y_i$$

Now, all two levels of every factor are equally represented in the eight experiments. Thus 'm' is a balanced overall mean over the entire experimental region.

The average S/N ratio for levels 1 and 2 for every parameter can be calculated by

$$m(P1)_1 = \frac{1}{4}(Y_1 + Y_2 + Y_3 + Y_4)$$

$$m(P1)_2 = \frac{1}{4}(Y_5 + Y_6 + Y_7 + Y_8)$$

The numerical values for 'Yi' can be substituted as above expression to obtain the values of the average n for each value of six parameters. They are listed in the table

Table6. Values of Noise & Vibration of Each Parameter from ANOM.

| Parameters | | Noise ( Min) | | Vibration ( Min) | |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 1 | Level 2 |
| P1 | Engine Bonnet | 55.7875 | 56.235 | 1.555 | 1.745 |
| **P2** | Vehicle Pay Load | 56.21 | 55.8125 | 1.4975 | 1.8025 |
| P3 | Road Profile | 54.3 | 57.7225 | 1.6525 | 1.6475 |
| P4 | Seat | 56.1025 | 55.92 | 1.5925 | 1.7075 |
| P5 | Air in Front Wheel | 55.9875 | 56.035 | 1.5825 | 1.7175 |
| P6 | Air in Rear Wheel | 55.905 | 56.1175 | 1.64 | 1.66 |
| P7 | Door sealing | 56.235 | 55.7875 | 1.61 | 1.69 |

**Optimum level is identified by yellow background.**

So optimum combination for

- Noise is P1(1)P2(2)P3(1)P4(2)P5(1)P6(1)P7(7)
- Vibration is P1(1)P2(1)P3(2)P4(1)P5(1)P6(1) P7(1)

## Analysis of Variance (ANOVA)

A better feel for the relative effect of various factors can be obtained by the decomposition of variance, which is commonly called analysis of variance (ANOVA).

Computation of Sum of Squares,

Computation of grand total sum of squares (G)

The sum of squared value of 'Y' is called 'Grand total sum of squares'

$$G = \frac{1}{8}\sum_{i=1}^{8} Y_i^2$$

- Sum of square due to mean (S)

The sum of squares due to mean is given by
$S = n * m^2$

- Total sum of Square (T)
  Total sum of squares T = G-S

Sum of squares due to parameters
The sum of squares due to parameter P1 is equal to the total squared deviation of the Parameter P1 from the line representing the overall mean since there are two experiments each at (P1)1 and (P1)2 the replication number.

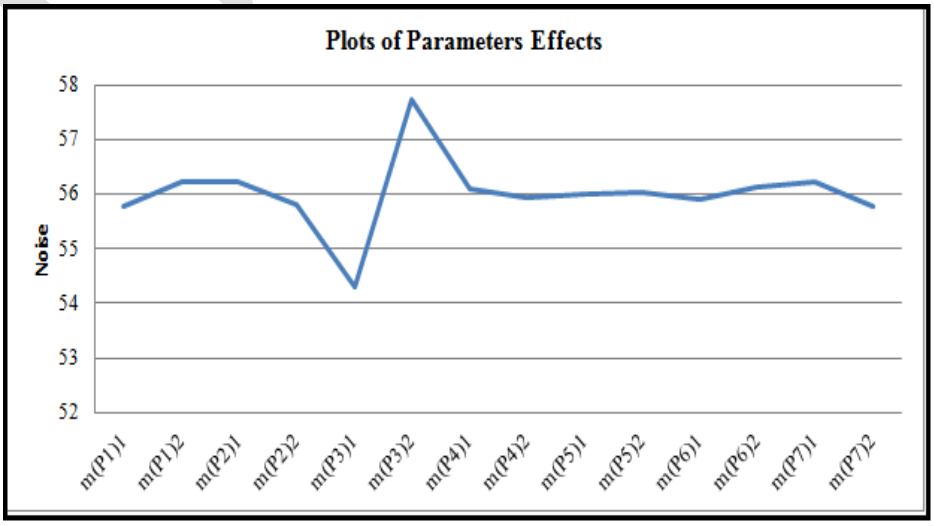
Sum due to P1 is:

$$S_1 = 2[m(P1)1 - m]^2 + 2[m(P1)2 - m]^2$$

Table7. Sum of Square for Each Parameter.

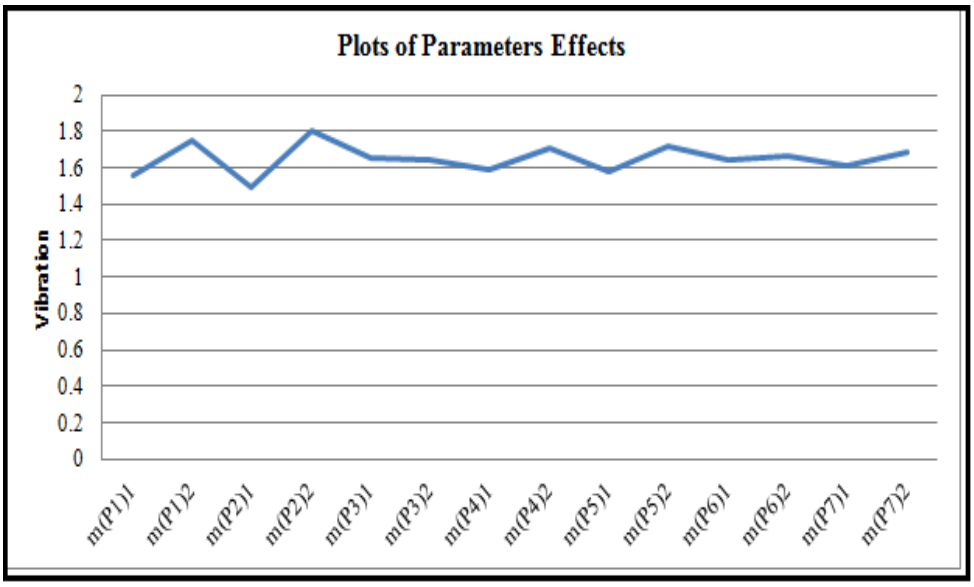
| Terms | | Noise | Vibration |
|---|---|---|---|
| **G** | **Grand Total Sum Square** | **25122.7865** | **22.1148** |
| **S** | **Sum of Square Due to Mean** | **25098.08101** | **21.78** |
| **T** | **Total Sum of Square** | **24.7054875** | **0.3348** |
| **Sum of Squares Due to Parameters** | | | |
| **S1** | **Sum due to P1** | **0.20025625** | **0.0361** |
| **S2** | **Sum due to P2** | **0.15800625** | **0.093025** |
| **S3** | **Sum due to P3** | **11.71350625** | **2.5E-05** |
| **S4** | **Sum due to P4** | **0.03330625** | **0.013225** |
| **S5** | **Sum due to P5** | **0.00225625** | **0.018225** |
| **S6** | **Sum due to P6** | **0.04515625** | **0.0004** |
| **S7** | **Sum due to P7** | **0.20025625** | **0.0064** |

Graph1. Graphical Representation of Effect of Parameter on Noise.



The above graph shows the effect of different parameter on noise.

Graph2. Graphical Representation of Effect of Parameter on Vibration.




The above graph shows the effect of different parameter on vibration.

After doing calculation the Analysis of Variance for each parameter for the case I (i.e. idle). It gives the % Contribution of each parameter for noise and vibration respectively. These results are tabulated in the following table 8 and table9. In the same way analytical calculation is carried out for remaining seven cases.

Table8. ANOVA Table for Noise from DOE Calculation.

| ANOVA Table For Noise | | | | | |
|---|---|---|---|---|---|
| **Source** | **Parameter** | **Degrees Of Freedom (DOF)** | **Sum of Square (S.S)** | **Mean Square ( S/N)** | **% Contribution** |
| **P1** | Engine Bonnet | 1 | 0.20025625 | 0.20025625 | **1.621147933** |
| **P2** | Vehicle pay load | 1 | 0.15800625 | 0.15800625 | **1.279118657** |
| **P3** | Road Profile | 1 | 11.71350625 | 11.71350625 | **94.82513753** |
| **P4** | Seat | 1 | 0.03330625 | 0.03330625 | **0.269626333** |
| **P5** | Air in front wheel | 1 | 0.00225625 | 0.00225625 | **0.018265173** |
| **P6** | Air in rear wheel | 1 | 0.04515625 | 0.04515625 | **0.365556438** |
| **P7** | Door sealing | 1 | 0.20025625 | 0.20025625 | **1.621147933** |
| | Error | 0 | | | |
| | Total | 7 | 12.35274375 | | |

Table9. ANOVA Table for Vibration from DOE Calculation

| ANOVA Table for Vibration | | | | | |
|---|---|---|---|---|---|
| **Source** | **Parameter** | **Degrees Of Freedom (DOF)** | **Sum of Square (S.S)** | **Mean Square ( S/N)** | **% Contribution** |
| **P1** | Engine Bonnet | 1 | 0.0361 | 0.0361 | **21.5651135** |
| **P2** | Vehicle pay load | 1 | 0.093025 | 0.093025 | **55.57048984** |
| **P3** | Road Profile | 1 | 2.5E-05 | 2.5E-05 | **0.014934289** |
| **P4** | Seat | 1 | 0.013225 | 0.013225 | **7.900238949** |
| **P5** | Air in front wheel | 1 | 0.018225 | 0.018225 | **10.88709677** |
| **P6** | Air in rear wheel | 1 | 0.0004 | 0.0004 | **0.238948626** |
| **P7** | Door sealing | 1 | 0.0064 | 0.0064 | **3.823178017** |
| Error | | 0 | | | |
| Total | | 7 | 0.1674 | | |

## Results Verifications with MINITAB 16 Software:

For the case I (Idle) result are verified by MINITAB 16 Software. Following screen shot shows analysis of variance for vibration for respective case.

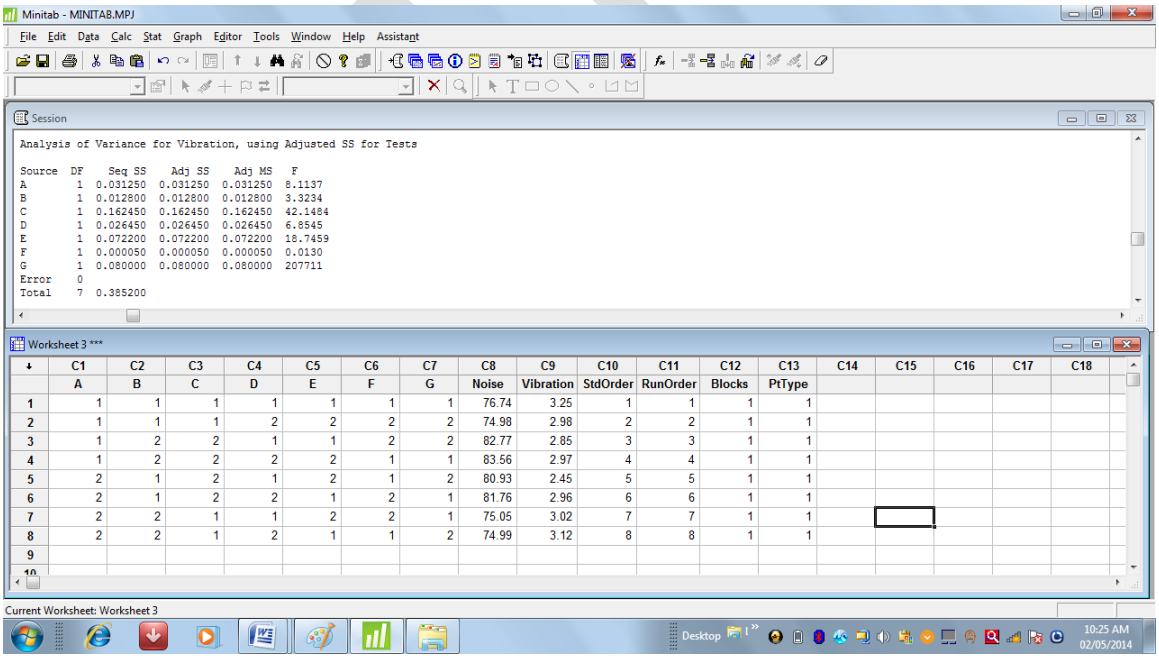



Fig 2: Screen Shot of MINITAB Soft.

Following table shows % Contribution of each parameter for noise and vibration respectively, i.e. output of MINITAB software.

Table10. ANOVA Table for Noise from MINITAB Soft. Output

| ANOVA Table For Noise | | | | | |
|---|---|---|---|---|---|
| **Source** | **Parameter** | **Degrees Of Freedom (DOF)** | **Sum of Square (S.S)** | **Mean Square ( S/N)** | **% Contribution** |
| **P1** | Engine Bonnet | 1 | 0.4005 | 0.4005 | **1.621103079** |
| **P2** | Vehicle pay load | 1 | 0.316 | 0.316 | **1.279072591** |
| **P3** | Road Profile | 1 | 23.427 | 23.427 | **94.82542278** |
| **P4** | Seat | 1 | 0.0666 | 0.0666 | **0.269576692** |
| **P5** | Air in front wheel | 1 | 0.0045 | 0.0045 | **0.018214641** |
| **P6** | Air in rear wheel | 1 | 0.0903 | 0.0903 | **0.365507136** |
| **P7** | Door sealing | 1 | 0.4005 | 0.4005 | **1.621103079** |
| Error | | 0 | | | |
| Total | | 7 | 24.7054 | | |

From the table 8 and 10 it is clear that % contribution of parameter for noise is varying by 0.000044854. This variation is negligible and accepted.

Table11. ANOVA Table for vibration from MINITAB Soft. Output

| ANOVA Table For Vibration | | | | | |
|---|---|---|---|---|---|
| **Source** | **Parameter** | **Degrees Of Freedom (DOF)** | **Sum of Square (S.S)** | **Mean Square ( S/N)** | **% Contribution** |
| **P1** | Engine Bonnet | 1 | 0.0722 | 0.0722 | **21.57155662** |
| **P2** | Vehicle pay load | 1 | 0.186 | 0.186 | **55.57215417** |
| **P3** | Road Profile | 1 | 0.00005 | 0.00005 | **0.014938751** |
| **P4** | Seat | 1 | 0.0264 | 0.0264 | **7.887660592** |
| **P5** | Air in front wheel | 1 | 0.03645 | 0.03645 | **10.89034957** |
| **P6** | Air in rear wheel | 1 | 0.0008 | 0.0008 | **0.239020018** |
| **P7** | Door sealing | 1 | 0.0128 | 0.0128 | **3.824320287** |
| Error | | 0 | | | |
| Total | | 7 | 0.3347 | | |

From the table 9 and 11 it is clear that % contribution of parameter for vibration is varying by 0.00114227. This variation is negligible and accepted.

## CONCLUSION

After comparing the result of DOE and Minitab 16 software it shows that variation in the % contribution of concerned parameter is very small. Also it implies that the methodology used for analysis is valid. From this work one can conclude that, every parameter have different contribution in creating noise and vibration in the vehicle compartment. If noise is taken in to account then road profile is the measure cause of creating noise with % contribution of **94.82513753.** And for the vibration vehicle pay load is more responsible for producing the vibration in vehicle compartment with % contribution of **55.57215417.** This is the individual analysis of each parameter. For finding best optimum condition which creates minimum vibration, FUZZY TOPSIS method can be used. It becomes extension to this work. It will give the best set of parameter having a minimum noise and vibration. It will help to reduce the noise as well vibration which is the final objective.

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