Taguchi Analysis to Optimise the Fuel Efficiency in a Public Transportation Company and Determining the Contribution of Different Parameters

Dr. Putta Bore Gowda[1], Dr. Prabhudev[2] and Dr. R.Chandrashekar[3]
[1]Department of Mechanical Engineering, Ramaiah Institute of Technology, Bangalore, pbgowda@msrit.edu.
[2]Departmentof labour secretary, BOCW, Govt of Karnataka Bangalore, prabhudevg@gmail.com
[3]Former Professor, Ramaiah Institute of Technology, Bangalore, rajchandras@gmail.com

ABSTRACT

Factors like type of road, age of bus, experience of driver, etc. determine the mileage derivable from a bus. The paper attempts to find the contributions of six selected parameters in determining the fuel efficiency of the bus and also to find the optimized parametric conditions for improving the fuel efficiency.

Data available from a reputed public transportation company were collected for over two years and analyzed using the Taguchi technique. It was found that the bus run km had the maximum impact of 34.5% on fuel efficiency, followed by the driver's age, which impacted 21.1%.

It could also be concluded that while the company buses were operating at high fuel efficiencies, a further improvement of about 12% (from 5.48 to 4.9 km/l) was possible by optimization of the controllable parameters, which would result in cost savings in addition to reduction in pollution..

Key words : Fuel Efficiency, Taguchi Analysis, Transportation, Cost Savings, Pollution Control.

1. INTRODUCTION

A typical public transport corporation in India has about 5000 buses, of various types like Ashok Layland, Volvo, etc. These buses travel on different roads like National highways, State Highways, city roads, hilly roads, etc., and carry about 300,000 passengers per day on the average. The total mileage of these buses is typically 1,700,000 km/day. The average consumption of fuel is between 4.5 and 5.0 km/l. the occupancy rate ranges from 65 to 100%, averaging about 85%.

Various parameters like the type of road, type of bus, etc. determine the fuel efficiency of the buses. If the fuel efficiency could be improved by 1%, there would be savings of about one million kL of diesel annually, which, at present rates would convert into cost savings of about Rs.65 million /year for the corporation.

The study presented in this paper details the methodology adopted for improvement in fuel efficiency of a large public transport corporation without resorting to any technical

2. SELECTION OF PARAMETERS

There are at least 20 parameters which affect the fuel efficiency. After detailed discussions with officials of the Corporation, seven parameters were selected as having major impact on the fuel efficiency.

Other parameters like the number of stoppages, average and maximum speed of bus, wind direction and wind speed, etc. were not considered in this study.

While bus age, bus run km, driver age, and season were parameters considered at three levels, bus type, road type, and driver experience were considered at two levels. Table 1 below details the parameters and levels considered.

Table 1: Parameters and levels

Parameter	Level-1	Level-2	Level-3
Bus type	Ashok Layland	Volvo	--
Road type	Good	Not so Good	--
Bus age	< 3	3 - 6	6 - 9
Bus run km	< 300,000	300,000 – 600,000	600,000 – 900,000
Driver age	< 35	35 - 45	45 - 55
Driver experience	< 10	10 -20	--
Season	Summer	Rainy	Winter

3. THE TAGUCHI APPROACH

In the past decade, the use of Taguchi method for designing experiments has gained ground, and many researchers have used this methodology successfully for various optimization situations [The method has also been employed for reverse

optimization, i.e., where the experimental results or operational data are already available and the appropriate Taguchi Orthogonal Array are fitted to the available data to determine the optimized conditions.

This methodology has been successfully employed for

a) Designing of experiments conducted in the laboratory
b) Designing of experiments in field
c) Optimization of parameters from available information / data from existing systems
d) Optimization of factors from survey-based information.

From available literature, the technique of Taguchi Orthogonal Array L'18 has been employed for optimization of parameters in situations of biodiesel usage, EDM process, plastic injection molding, cutting parameters in turning, electrical discharge machining, green sand casting process, recycling of aluminum, etc [1-9]. However, use of this technique in transportation is very rare.

3.1 Taguchi Orthogonal Array Selection

For the combination of seven parameters with maximum three levels, the L'18 orthogonal array was found to be suitable, as given in Table 2.

Table 2: Taguchi Orthogonal Array L'18

Sl.No.	Parameter						
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2
3	1	1	3	3	3	1	3
4	1	1	1	3	2	2	3
5	1	2	2	1	3	1	1
6	1	2	3	2	1	2	2
7	2	2	1	2	3	1	2
8	2	2	2	3	1	2	3
9	2	1	3	1	2	1	1
10	2	1	1	2	1	2	1
11	2	1	2	3	2	1	2
12	2	1	3	1	3	2	3
13	3	1	1	1	2	1	3
14	3	2	2	2	3	2	1
15	3	2	3	3	1	1	2
16	3	2	1	3	3	2	2
17	3	2	2	1	2	1	3
18	3	2	3	2	1	2	1

3.2 Taguchi Orthogonal Array L'18 Applied To Operational Data:

The orthogonal array [Table 4.55] applied to the actual performance data and the response thereof in terms of KMPL

is shown in Table 4.56. The S/N Ratios have also been calculated and included in Table 3.

Table 3: L'18 Orthogonal Array applied to Operational Data

Parameter							Avg KMPL	S/N Ratio for KMPL
Bus Type	Road Type	Bus Age	Bus Run Km	Driver Age	Driver Exp	Season		
1	1	3	3	35	10	1	4.41	1.289
1	1	6	6	45	20	2	4.99	1.396
1	1	9	9	55	10	3	4.69	1.342
1	1	3	9	45	20	3	4.55	1.316
1	2	6	3	55	10	1	5.05	1.407
1	2	9	6	35	20	2	5.03	1.403
1	2	3	6	55	10	2	5.13	1.420
1	2	6	9	35	20	3	4.56	1.318
1	1	9	3	45	10	1	4.80	1.362
2	1	3	6	35	20	1	4.58	1.322
2	1	6	9	45	10	2	4.58	1.322
2	1	9	3	55	20	3	5.60	1.496
2	1	3	3	45	10	3	5.29	1.447
2	2	6	6	55	20	1	5.05	1.407
2	2	9	9	35	10	2	4.74	1.352
2	2	3	9	55	20	2	4.79	1.361
2	2	6	3	35	10	3	4.99	1.396
2	2	9	6	45	20	1	5.43	1.470

The mean S/N Ratio for each level has been calculated and is summarized in Table-IV. The total mean S/N Ratio for the 18 sets was also calculated.

Table 4: Response Table for Mean S/N Ratio for KMPL

SYMBOL	PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	Optimum Level (max. S/N Ratio)
B	Bus Type	1.361535	1.396818		B2
R	Road Type	1.365853	1.392499		R2
BA	Bus Age	1.359075	1.374205	1.404249	BA-3
BKM	Bus Run	1.399572	1.402914	1.335043	BKM-2

	KM				
DA	Driver Age	1.346572	1.385491	1.405466	DA-3
DE	Driver Exp.	1.370769	1.387583		DE-2
S	Season	1.375976	1.375588	1.385964	S-3

Total Mean S/N Ratio = 1.379176 dB. The response graph drawn using the values from the response table is shown in Figure(1).
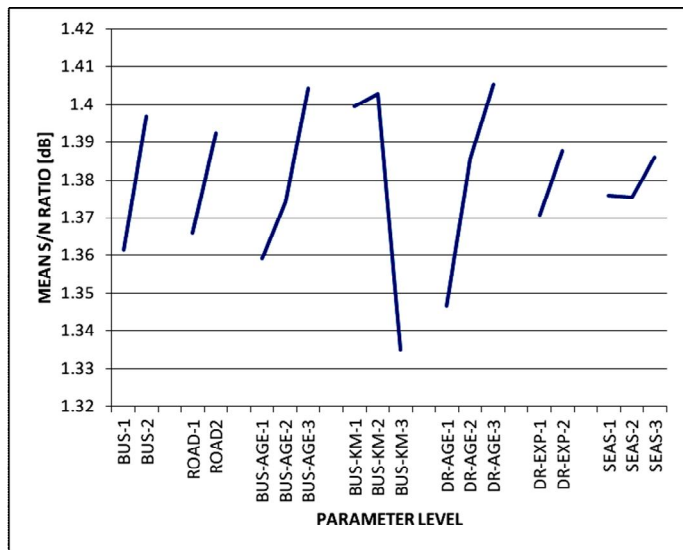

Figure 1: Response Graphs for KMPL

The optimum levels of parameters for obtaining maximum KMPL are also available in Table 4, which are: Bus type 2, Road type 2, Bus age 6-9 yrs., Bus run km 2, driver's age 45-55 yrs., driver experience 10-20 yrs., and season 3. .

3.3. Analysis of Variance (ANOVA)
The contributing ratio of parameters in obtaining maximum KMPL as brought out by ANOVA is shown in Table 5, and the corresponding Pareto ANOVA Diagram is shown in Figure(2).

Table 5: Results of Analysis of Variance for KMPL

| SOURCE	DOF	SOS	VAR	TRUE VAR	F-RATIO	CONT,%
BUS	1	0.001877	0.000934	-0.00272	0.406938	7.3
ROAD	1	0.001065	0.000533	-0.00352	0.232094	4.2
BUS AGE	2	0.003172	0.001586	-0.00142	0.691329	12.4
BUS KM	2	0.008782	0.004391	0.004193	1.913729	34.5
DRIVER AGE	2	0.005382	0.002691	0.000793	1.172891	21.1
DRIVER EXP	1	0.000424	0.000212	-0.00416	0.092415	1.7
SEASON	2	0.000208	0.000104	-0.00438	0.045237	0.8
ERROR	2	0.004589	0.002294			18.0
TOTAL		0.025489		-0.01122		100
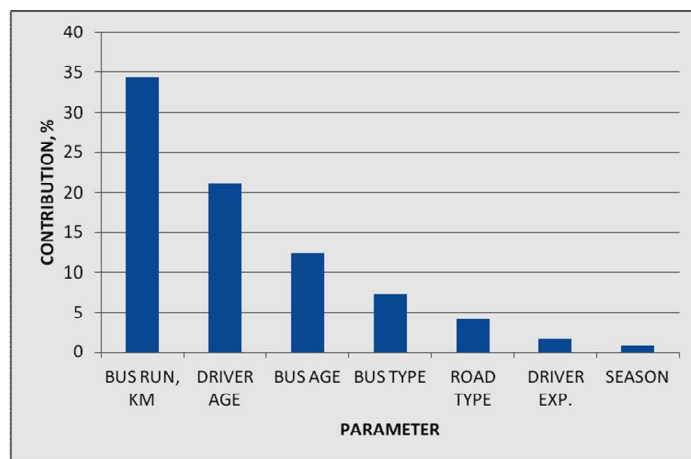
Figure 2: Pareto Analysis for KMPL

It is seen that the effects of season, driver experience and road type on the fuel efficiency [KMPL] is low or negligible, whereas the parameters like Bus run-KM, driver age and Bus age influence the KMPL very significantly. Bus type, with a contribution of   7.3%, is also not a very significant determinant parameter.

3.4. Prediction of Optimum Performance

At the optimum setting conditions, the optimum Fuel Efficiency [KMPL] was calculated to be 5.48 ± 0.19 KMPL.

3.5 Other methods for improving fuel efficiency:

There have been many other approaches towards increasing fuel efficiency. For example Adnan et. al [11] have used ultrasonic sensors for monitoring vehicle blind spots, and Iswanto et. al[10] used additives to fuel for improving the fuel efficiency.

4. CONCLUSION

The Taguchi approach has resulted in the following conclusions:

1) Of the seven parameters selected as the major influencing factors in determining the fuel efficiency of a public road transport corporation, three factors were found to have significant effects, whereas the other four had insignificant effects.

2) The three parameters which had significant effects were:
   a) Us Run KM   - 34.5%
   b) Driver Age - 21.1%
   c) Bus Age   - 12.4%

The four parameters which were found to be not so significant were:
   a) Bus Type   - 7.3%
   b) Road Type   - 4.2%
   c) Driver Experience - 1.7%
   d) Season   - 0.8%

3) If a proper combination of parameters could be selected for the operation, the fuel efficiency as measured by the km per liter of diesel [KMPL] would increase from the present 4.9 KMPL to 5.48 KMPL, an increase of 12%. There would be a corresponding decrease in pollution from the fleet., as well as cost savings.

4) The Taguchi based approach provides an effective technique for analyzing and optimizing operational parameters in the transport industry.

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