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Technical and Economic Optimization of Urban Bus System Based On Automatic Vehicle Location

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ABSTRACT: *Control and management of the cars moving in urban bus system and information data about their position in time are very important. For this purpose automatic vehicle location (AVL) system have been used in recent years. In spite of good performance of this system, it has high price and should be optimized. Therefore, coupled response surface methodology and genetic algorithm was used for optimization in this research. Bus repairing is one of the most expensive expenditure of the cars. Therefore, for optimization of bus usage in a line, the optimum conditions can be determined and as a results the side costs and repair costs decrease. Different conditions may destroy the cars such as non-allowed speed, intense brake, non-allowed stop, exit of line, weak antenna, abnormal acceleration, and bus type. To determine the optimum conditions, at first, a relation among sent to repair shop and this conditions was determined using response surface methodology. Then the relation was used as the fitness function in genetic algorithm. The results of optimization showed that the best number of non-allowed speed, intense brake, non-allowed stop, exit of line, weak antenna, and abnormal acceleration were 42.3, 21.3, 6.3, 23.9, 14.62, and 50.98, respectively. With this condition ranges, number of sending car to repair shop decrease, intensely and reach near to zero. Given that all the buses under consideration were repair shops, achieving absolute zero was not possible. But too small amounts close to zero based on the model are also sufficient for us*

Keywords: *Automatic vehicle location system, genetic algorithm, modeling, optimization, response surface methodology.*

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I. INTRODUCTION

Automatic Vehicle Location (AVL) systems for public transit have become readily available in the last several years and have been utilized to track the locations of transit vehicles in real time. They have been promoted as being beneficial to the transit industry by offering transit agencies more flexibility in monitoring and managing their vehicles and by reducing customers’ wait time and increasing riders’ (perceived) security (Gomez et al., 1998). These systems are being implemented primarily in large transit systems such as bus system where the AVL can provide obvious efficiencies in managing a large fleet of vehicles (Casey et al. 1998).

Many studies in the literature focus on the development of the AVL technology. For example, Cain and Pekilis (1993) in their article on the development history of AVL give a good description of the shift from Loran et al. to the present global position systems (GPS) with enhanced real time location tracking and schedule monitoring. Dana (1997), Okunieff (1997) and Khattak et al. (1998) also provide a good overview of the GPS technology and the role of AVL for bus transit. These studies on AVL systems highlighted the fact that GPS was the most popular technology available in the market at present. A wide variety of features can be added to the basic AVL system. Smart cards, electronic billing, passenger counters, maintenance monitoring system, etc., are some of the examples. On the other hand, very limited literature is available on the cost-benefit analysis for the applications of AVL systems in transit agencies. One reason for this could be that it is a relatively new technology, and there is little data available for detailed cost-benefit analysis. Therefore the AVL data were

gathered on urban bus system in this research based on cost benefit analyses. Gomez et al. (1998) cite the example of six transit agencies in their paper and highlight the different service configurations, fleet, objectives, and other requirements that would determine the cost of an AVL system. Their survey of transit agencies using AVL and those in the implementation stage showed that improving schedule adherence, emergency response and providing real-time travel information were the three most important factors in opting for AVL technology.
Different methods can be used for optimization of conditions. The most popular method is genetic algorithm. The Genetic Algorithm (GA) have been widely used in civil and transportation engineering (Putha et al., 2012; Ranjitkar et al., 2005). It has been tested for its applicability in traffic engineering (Bagula and Wang, 2005), environmental modeling and soil mechanics; however, not much attention is given to its applicability in public transportation. Recently, Rashidi and Ranjitkar (2015), investigated the application of the GA to model and estimate bus dwell time. They conclude that there is a prospect for improving bus dwell time modelling using their proposed GA approach. Therefor the goal of the present work is to optimize the technical and economic conditions of urban bus system using genetic algorithm based on AVL data acquired of Esfahan town.

II. MATERIALS AND METHOD

2.1 Data selection

Data collection was performed using the AVL system installed in the bus system of Isfahan province. The researches show that the AVL system is a strong system but its problems was founded by time. One of the most obvious problems is its ruin including receiver and transmitter system damages and therefore needs repair. Furthermore their repair is costly and so decrease the quality of system. These problems include the repair of parts that are in the worst repair condition. Totally various factors may cause to destroy the bus during the work which can effect of how to derive, sudden pressures (for example sudden acceleration, intense brake, and so on), buses rest, bus type, and so on. For technical optimization of this system, it should be tried to attach the least destroying and repair. Therefore four types of buses were considered in an important line of Esfahan town. Furthermore, the sudden pressures and problems were studied in this line for 7 days. Total number of buses were 34. The effective factors considered in this research were non-allowed speed, intense brake, non-allowed stop, battery destroy, exit of line, weak antenna, abnormal acceleration, and bus type. Totally 9235 warning message were studied of the AVL system mounted on the buses. These conditions led to 346 times need to repair shop. The warning messages were studied separately according to frequency of each message based on bus code and absolute frequency of each message (the number of each message) for each bus type were noted. Then the absolute frequency of each factor (warning message) was selected as benchmark of that factor. Therefore the absolute frequency of each factor was used instead of that factor. In the following for optimization of bus usage in a line, the optimum conditions was determined and as a results the side costs and repair costs decreased. To determine the optimum conditions, at first, a relation among sent to repair shop and the conditions led to repair was determined, then the relation was used as the fitness function in genetic algorithm. By minimizing the fitness function using the genetic algorithm, the best conditions is determined.

2.2 Fit function

Different parameters affect the side costs and repair costs. Some of them were determined in this research. To determine a model for estimation the repair need at first correlation among the repair need and the selected parameters were determined and then the parameters which were correlated significantly at level 5% and 1% were finally selected for modelling. The correlation coefficients were illustrated in Table 1.
As it is shown in Table 1, send to repair shop was significantly correlated with non-allowed speed, intense brake, exit of line, and antenna weak at level of 1%. Furthermore it was significantly correlated with abnormal acceleration at level of 5%. Totally the factors not significantly correlated at levels of 1% and 5%, have low effect on send to repair shop. As shown, the buses did not go to the repair shop to fix the warning message of the weak battery and the failure of the electronic payment device. Below the model is made according to the important parameters.

Table I: Correlation coefficients of absolute frequency of considered parameters

	Repair shop	Non-allowed speed	Intense brake	Non-allowed stop	Battery destroy	Exit of line	Antenn a weak	Destroy of PW9000	Abnormal acceleration	Bus type	Bus code
Repair shop	1	.731**	.713**	.519**	.019	.526**	.549**	.135	.340*	-.455**	.386*
Non-allowed speed		1	.668**	.598**	.093	.612**	.527**	.145	.475**	-.496**	.470**
Intense brake			1	.578**	-.170	.619**	.568**	.144	.725**	-.533**	.473**
Non-allowed stop				1	.096	.970**	.411*	-.447**	.469**	-.450**	.364*
Battery destroy					1	.096	.268	-.043	.024	-.008	-.079
Exit of line						1	.447**	-.476**	.496**	-.414*	.331
Antenna weak							1	.147	.291	-.394*	.258

Damage to electronic payment device	1	.096	-.148	.150
Abnormal acceleration		1	.966	.658
Bus type			1	-.585**
Bus code			-.585**	1

* Correlation at level of 5% ** Correlation at level of 1%

To determine the fit function, different methods such as regression and response surface methods (RSM) can be used (DuMouchel and Jones, 1994; Goos and Donev, 2010). The RSM determine a model based on optimization, therefore it was used for modelling the repair shop need. For this purpose dependent variable y(x), the number of send to repair shop, was modeled according to independent variables xi, or consideration parameters. Repeat the information for modelling was done according to gathered information from 34 different buses. Among considered models, the model with the least error was selected as the fitness function for genetic algorithm. The considered models were linear (Eq. 1), iteration (Eq. 2), pure quadratic (Eq. 3), and full quadratic (Eq. 4) models (Shrivastava and Dhingra, 2002).

$$y(x) = a_0 + \sum_{i=0}^{N} a_i x_i, i = 1, 2, ..., N \tag{1}$$

$$y(x) = a_0 + \sum_{i=1}^{8} a_i x_i + \sum_{i=1}^{8} b_i x_i^2, i = 1, 2, ..., 8 \tag{2}$$

$$y(x) = a_0 + \sum_{i=1}^{6} a_i x_i + \sum \sum_{i<j}^{6} b_{ij} x_i x_j, i = 1, 2, ..., 6 \tag{3}$$

$$y(x) = a_0 + \sum_{i=0}^{6} a_i x_i + \sum_{i=1}^{6} b_i x_i^2 + \sum \sum_{i<j}^{6} c_{ij} x_i x_j, i = 1, 2, ..., 6 \tag{4}$$

III. Results and Discussion

The results show that 70.87% of bus speeds was bellow that 5 km/hr, 28.35% of bus speeds was between 5 and 10 km/hr, and 0.79% of bus speeds was more than 10 km/hr. Modelling was done in two modes, modeling based on warning including with bus type and modeling based warning.

3.1 Modeling based on warnings including with bus type

In this case, the dependent variable y(x) was sent to repair shop and the independent variables were non-allowed speed x1, intense brake x2, non-allowed stop x3, exit of line x4, antenna weak x5, abnormal acceleration x6, bus type x7, and bus code x8. Given that the repetition was 34 and the variables was high, the linear model and pure quadratic model just could be used for modeling. The results show that the pure quadratic model was more accurate than linear model. Therefore the pure quadratic model is considered in the following. The pure quadratic model was Eq. 2 and its coefficients were illustrated in table 2. Root mean square error (RSME) of the model was 3.89 calculated according to reference (Kan, 2015). Figure 1 shows the trend of repair need cross the independent variables.

Table II: Coefficients of pure quadratic model for modeling send to repair shop based on warnings including with bus type

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
-19.002	0.117	0.225	0.908	-0.269	-0.298	0.024	12.552	0.012
	$b1$	b_2	b_3	b_4	b_5	b_6	b_7	b_8
	-0.0004	-0.0001	-0.013	0.0006	-0.004	-0.0004	-2.78	-2.54E-06

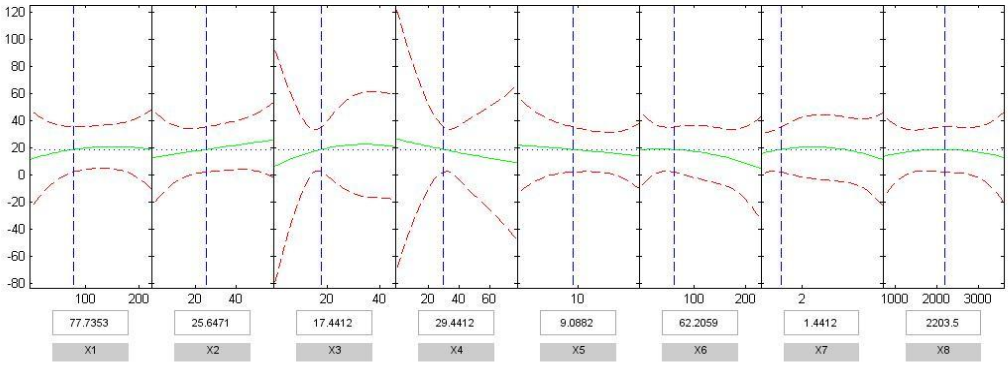

Fig 1: Need to repair shop estimated with pure quadratic model and its changes versus warnings including with bus type

As it is illustrated in Fig. 1, the trend of changing the repair need in ranges of considered independent variables reach to its minimum value, therefore this model can be used as the fitness function in GA. Fig. 1 shows that the best bus type (x7) was 1.44 and by thresholding value of 0.5, we could select the bus type of Benz was the best bus for using in the line 34 more robustly. The graphs in Fig. 1 were the contour graph of changing the repair need according to the considered factors and drawing for each factor by substituting zero for the other variables.

3.2 Modeling based on warnings

In this case, the dependent variable y(x) was sent to repair shop and the independent variables were non-allowed speed x1, intense brake x2, non-allowed stop x3, exit of line x4, antenna weak x5, abnormal acceleration x6. The repetition was 34 and the independent variables was 6, therefore we can model the repair need by four proposed models. The results of modeling show that the linear modeling had low accuracy as RMSE of model was 4.24. The results of pure quadratic modeling show that its accuracy was better that linear modeling as its accuracy was 3.85. These results show that the accuracy of modeling based on warnings was similar to the modeling based on warnings including with bus type. The results of iteration model showed that its accuracy was more than the accuracy of linear and pure quadratic models as the RMSE of model between estimated repair need and real repair need was 2.31 and was lower than the others. The iteration model towards changes of independent variables was more sensitive than other models as had more especially minimum. The full quadratic model was the most accurate model among the considered models in this research as its RMSE was 1.71 and was lower than the other models. Its function was Eq. 4 and its coefficients are illustrated in table 3. Therefore it can be used for estimation the repair need very well. The trend of repair need using full quadratic model according to independent variables (considered factors) are illustrated in Fig. 2. As it is shown the trends of each graph were univariate than other models. As a results it can present a better optimum points.

Table III: Coefficients of full quadratic model for modeling send to repair shop based on warnings

a_0	a_1	a_2	a_3	a_4	a_5	a_6
0.879	0.159	-0.387	1.079	-0.385	-0.249	0.364
$b1$	b_2	b_3	b_4	b_5	b_6	c_1
-0.001	0.010	-0.004	0.009	-0.002	-0.087	0.053
c_2	c_3	c_4	c_5	c_6	c_7	c_8
-0.021	0.004	0.002	0.025	0.042	-0.036	-0.024
c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
-0.020	-0.001	0.012	-0.046	0.008	0.066	-0.002

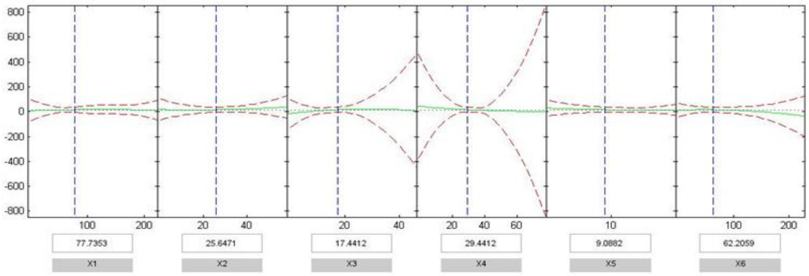

Fig 2: Need to repair shop estimated with full quadratic model and its changes versus six parameters of warnings

The results illustrated in Fig. 2 shows that for some points especially border points, the estimated values were higher than it real values. Therefore the Eq. 4 was divided to 15 (among different considered values) and decreased the values of border points while kept trends (Shrivastava and Mahony, 2009). In the following the estimated values cross the real values are illustrated in Fig. 3. As it is shown R-squared (R2) equaled to 0.75 which was good accuracy for a model (Seyrafinejad, 2017). This model was proposed between repair need and bus conditions driving for the first time and can be used in the following researches. This model was used as the fitness function for genetic algorithm.

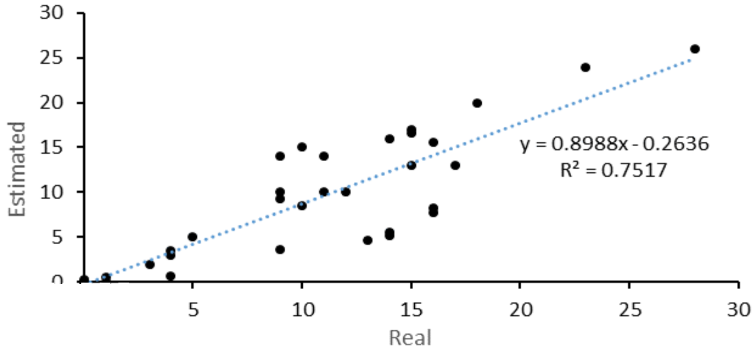

Fig 3: The number of real cases of sent to repair shop versus their estimated cases with full quadratic model based on warnings

3.3 Determination of optimum conditions of factors

The full quadratic model (Eq. 4) which had the most accuracy for estimation the repair need was used in genetic algorithm as the fitness function. The other genetic algorithm parameters were adjusted as following. The number of independent variables was 6, lower and upper bounds were 0 and 100, population size equaled to the number of stations, mutation coefficient was 0.3, crossover coefficient was 0.9, and the number of optimized generation was 50. By using the genetic algorithm according to adjusted parameters, the algorithm was running until the fitness function was minimized. Charts related to scores and validation of genetic algorithm are illustrated in Fig. 4.

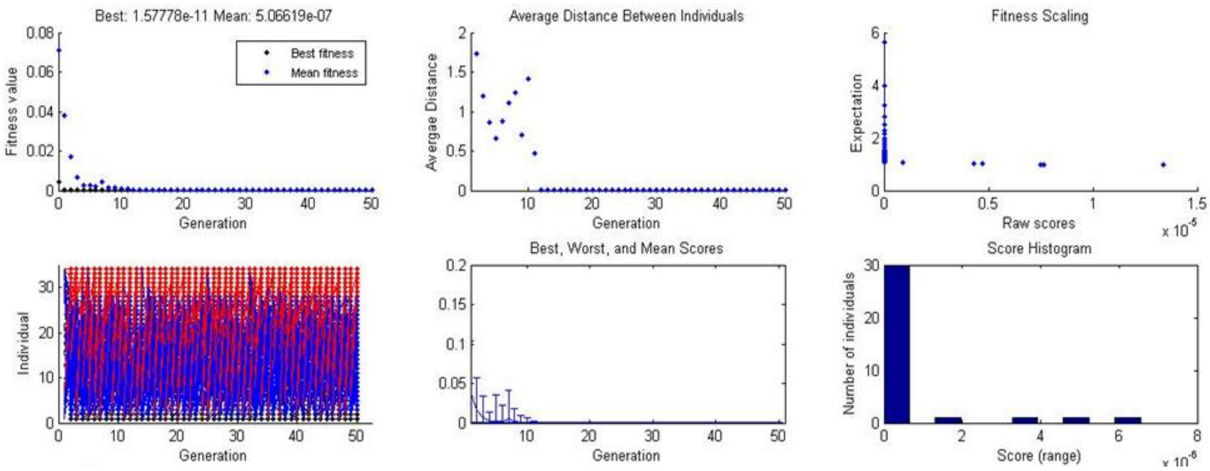

Fig. 4: Charts related to scores and validation of genetic algorithm for determination of optimal conditions of transportation of buses in line 34

In the Fig. 4, best fitness plot is the best function value in each generation versus iteration number. Distance plot is the average distance between individuals at each generation. Best individual plot is the vector entries of the individual with the best fitness function value in each generation. Expectation plot is the expected number of children versus the raw scores at each generation. Range plot is the minimum, maximum, and mean fitness function values in each generation. Score diversity plot is a histogram of the scores at each generation. As it is shown the score at sequential generations have been better and the number of children decreased, too. Furthermore the fitness values at sequential generations have decreased which shown available estimation by genetic algorithm. As the figure shown the distances in each generation have decreased and scores in each generation have increased. This conditions shows the genetic algorithm can determine the optimum values of six effective factors. The optimum numbers of non-allowed speed x1, intense brake x2, non-allowed stop x3, exit of line x4, antenna weak x5, abnormal acceleration x6 were 42.3, 21.3, 6.3, 23.9, 14.62, and 50.98, respectively. Furthermore the flag of results reach to zero. With this values for conditions, the least amount of repair need was made. Therefore with control the conditions in this values by drivers, the bus repair decreases and therefore urban bus system is optimized. Although we did not find similar researches, there were some researches for optimization the efficiency of buses. Mao and Iravani (2014) analyzed a trend-oriented power system security based on load profile. They make a model based on information of 30 buses and then determine the optimum conditions. Their optimization method is similar to our method. Huang (2016) purpose a new model for estimation of energy consumption by electrical buses. The model related to the parameters of maximum received power, stop time, active buses in line, line length, received energy, and so on. His methods and results were similar to the methods and results in this research. Therefore it can be trust to the results and methods used in this research and by coupling the results with other researches, it can be attached to better methods and results.

IV. CONCLUSION

The buses used in a line effect of environment conditions and driver work. This conditions cased to stresses on the buses and can destroy it. Repair the buses is costly and therefore increase the cost of transportation. To decrease the costs, it should be decreased the repair need. For that the best condition was determined. To determine the best conditions, a relation was made among the number of repair need (send to repair shop) and the effective parameters. Therefore the RSM was used for modelling the conditions. Four models including linear, iteration, pure quadratic, and full quadratic models were used. By consideration the estimated and real values, it was concluded that the full quadratic model had the most accuracy and after that was the pure quadratic. The results of genetic algorithm showed that the optimum numbers of non-allowed speed, intense brake, non-allowed stop, exit of line, antenna weak, abnormal acceleration were 42.3, 21.3, 6.3, 23.9, 14.62, and 50.98, respectively. With this values for conditions, the least amount of repair need was made. Therefore with control the conditions in this values by drivers, the bus repair decreases and therefore urban bus system is optimized.

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