1.1 Literature Review

Partha Chakraborty et al. [1] examined the possibility of using transit vehicle (buses) as probe vehicle for collecting data. They measured the travel time of transit vehicles and automobiles along the same sections on major corridors in Delaware. They developed a procedure that predicts the average travel time of the automobile, based on observed travel time of a bus in the same traffic stream. They compared bus travel time to automobile travel time and suggested a functional form that predicts the automobile travel time as based on the travel time of the bus. Sathya Prabha et al. [6] evaluated the operational efficiency of urban road network using travel time reliability measures. They estimated the measures from average travel time and 95th travel time. They developed travel time models as a function of traffic volume, speed, and distance and validated the travel time measures.

Charlie et al. [2] quantified the additional time required by buses due to traffic congestion. The basic approach involved developing a model that estimates bus travel time as a function of overall car travel time. The model was then used to estimate the proportion of bus travel time due to the increase in traffic time over free-flow conditions. They developed a regression model, which estimate the travel time rate of bus. It was expressed as a function of car travel rate, number of passengers boarding per minute, No. of bus stops per mile etc. This model was used to estimate the bus travel time rate, if cars were travelling under free flow conditions and the results were compared with observed bus travel times.

Faruk et al. [4] provided a comprehensive review of the current usage of GPS data in transportation planning applications and present a practical integrated methodology for using a robust source of GPS data, for commercial vehicle travel time prediction. They collected truck GPS data and taxi GPS data. A comparison with observed truck travel times collected from a limited source of truck-GPS data reveals that travel times obtained from taxi-GPS data approximate those of trucks, and can be used to supplement truck-GPS travel time data on a wider scale.

1.2 Objectives

The objectives of the study are:

- To develop a model that estimate Bus travel time as a function of car travel time
- To develop a model that estimate Car travel time as a function of bus travel time
- To verify the model by the data collected
2. STUDY AREA
The study route selected for the work was an urban stretch (Fig.1 Sreekaryam to East Fort via Kesavadasapuram comprises of approximately 10 km) in Thiruvananthapuram city which is the state capital and southern part of Indian subcontinent.

![Figure 1: Study route (not in scale)](image)

The study route has been divided in to 9 stretches based on major bus stops or junctions.

3. METHODOLOGY
Study route was classified into three segments based on geometric and traffic factors. Survey was done for 19 weekdays. Data collection was carried out using handheld GPS. Data collected are travel time, dwell time and traffic volume. The Map source software was used for extracting data from GPS device. Linear regression analysis was used to develop bus and car models. The models were validated using MAPE (Mean Absolute Percentage Error).

4. DATA COLLECTION
The survey was carried out during the morning peak hours. The data consists of 19 days travel time data of all modes of vehicles like public transit, two wheelers, three wheelers and four wheelers. The secondary data was used for identifying the parameters which influences the travel time prediction. After identifying the parameters, data was collected by taking videos at each segment of the study routes during the morning peak hours. The Map source software was used for extracting data from GPS device. The logged data includes time of arrival and departure, position, length, speed of travel etc. Secondary data includes the road inventory data was collected from NATPAC (Transportation Research Centre) Trivandrum.

5. DATA ANALYSIS
From the data, time taken by each vehicle to travel through the study route was calculated. In order to incorporate parameters like geometric factors, traffic factors, dwell time etc., logical segmentation of the study route was necessary. Some of the factors that influence route segmentation are Geometric factors, Traffic Factors etc. Based on these factors and road inventory data from NATPAC, the study route was classified into three stretches as shown in the table 1 given.

| Parameters          | segment1          | segment2          | segment3          |
|---------------------|-------------------|-------------------|-------------------|
| Sreekaryam -        | Kesavadasapuram   | Palayam -         |                   |
| Kesavadasapuram     | Kesavadasapuram   | Palayam -         | Eastfort          |
| Length of the route | 3.8Km             | 4.4Km             | 3.2Km             |
| Width of the road   | 7m                | 14m               | 14m               |
| No. of Lanes        | 2 lane (undivided)| 4 lane (divided)  | 4 lane (divided)  |
| Type of road        | NH 47             | MG road           | MG road           |
| Land Use            | Commercial/Residential | Commercial/Public | Mixed             |
| Shoulder Type       | Earthen shoulder  | Footpaths on both sides | Footpath s on both sides |
| Traffic volume      | 3964 veh/hr       | 4400 veh/hr       | 6412 veh/hr       |
| Parking             | No separate parking lots | On street parking/off street parking facilities | On street parking |
| No. of bus stops    | 4                 | 5                 | 4                 |

5.1 Model development
The linear relationship between travel time(dependent variable) and the influencing factors (independent variables) was computed by using the multiple linear regression equation. Linear regression is one of the most widely studied and applied statistical and econometric techniques. R² is used to account for the changes in the degrees of freedom. This approach is a general and flexible approach for testing the statistical difference between competing models.

5.1.1 Bus Travel Time Model
A Linear regression model was developed using SPSS (Statistical Package for the Social Sciences) software. Bus travel time (BTT) was taken as dependent variable. Application of bus travel time model is to predict the bus travel time with the help of other independent parameters. Some of the important parameters which affect bus travel time are car travel time, dwell time and volume of traffic etc. Bus travel time can be expressed as function of car travel time, dwell time and volume. But here, dwell time was avoided in modeling bus travel time because the assumption is that in future all vehicles(car) will be equipped with GPS there by car travel time can be easily determined. Traffic volume is another independent parameter which can also be determined easily. But the effect of dwell time of bus is not considered since we are modelling bus travel time as a function of car travel time.
Sreekaryam - Kesavadasapuram
\[ BTT = 1.391 + 0.878(Car\ travel\ time) + 0.277(volume) \]

Kesavadasapuram - Palayam
\[ BTT = 2.484 + 0.257(car\ travel\ time) + 0.760(volume) \]

Palayam - Eastfort
\[ BTT = 2.849 + 0.835(Car\ travel\ time) + 0.023(volume) \]

5.1.2 Car Travel Time Model
Car travel time models are used for predicting car travel time as a function of bus travel time. Car travel time (CTT) was taken as dependent variable and Bus travel time, Dwell time of the bus and volume were taken as independent variables. Government of Kerala is equipping all KSRTC buses with GPS units as part of strengthening the Kerala State Road Transport Corporation. Once this is implemented the bus travel time and dwell time of the buses can be easily determined. By knowing the traffic volume the car travel time can be expressed as a function of these parameters. Correlation matrix obtained for car as well as bus was found out that all parameters are moderately correlated to each other. The table below shows the results of parameter estimation of the model.

\[
\begin{align*}
\text{Sreekaryam - Kesavadasapuram} & : \\
\text{CTT} &= 1.225 + 0.263(BTT) + 1.030(Dwelltime) + 0.131(volume) \\
\text{Kesavadasapuram – Palayam} & : \\
\text{CTT} &= 0.636 + 0.232(BTT) + 2.238(Dwelltime) + 0.046(volume) \\
\text{Palayam–Eastfort} & : \\
\text{CTT} &= 0.386 + 0.272(BTT) + 0.293(Dwelltime) + 0.080(volume)
\end{align*}
\]

Table 3: Model parameter estimates (Sreekaryam - kesavadasapuram)

| Model | Variables           | \( \beta \) | t-statistic |
|-------|---------------------|-------------|-------------|
| Bus   | Constant            | 2.484       | 1.154       |
|       | Car travel time     | 0.257       | 1.790       |
|       | volume              | 0.760       | 3.707       |
|       | \( R^2 \)           | 0.642       | 1.734       |
|       | t-table             |             |             |
| Car   | Constant            | 0.636       | 0.267       |
|       | Bus travel time     | 0.232       | 1.904       |
|       | Dwell time          | 2.238       | 2.942       |
|       | Volume              | 0.046       | 1.757       |
|       | \( R^2 \)           | 0.586       | 1.734       |
|       | t-table             |             |             |

5.2 Model Validation
Mean Absolute Percentage Error was used to validate the developed models. It is defined as the percentage of the absolute difference between the field data and the predicted data. MAPE is given by

| Model | Variables           | \( \beta \) | t-statistic |
|-------|---------------------|-------------|-------------|
| Bus   | Constant            | 2.489       | 2.466       |
|       | Car travel time     | 0.878       | 3.015       |
|       | volume              | 0.277       | 1.751       |
|       | \( R^2 \)           | 0.725       | 1.734       |
|       | t-table             |             |             |
| Car   | Constant            | 1.225       | 1.046       |
|       | Bus travel time     | 0.263       | 1.735       |
|       | Dwell time          | 1.030       | 1.833       |
|       | Volume              | 0.131       | 1.943       |
|       | \( R^2 \)           | 0.788       | 1.734       |
|       | t-table             |             |             |

Models developed are shown below.

Sreekaryam - Kesavadasapuram
\[
\text{CTT} = 1.225 + 0.263(BTT) + 1.030(Dwelltime) + 0.131(volume)
\]
MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{\text{field data} - \text{simulated data}}{\text{field data}} \right| \times 100

n = Number of samples

MAPE value of

0-10% = Very Good
10-20% = Good
20-30% = Satisfactory

Bus travel time and car travel time were taken for another 5 days for the same stretch. Developed models were validated by using this data. MAPE obtained for three stretches are shown below. MAPE values of all the stretches are found to be in between 0 and 20 and the models were found to be good.

Table 5: MAPE of the three stretches

| MODES | MAPE          |
|-------|---------------|
| Sreekaryam - Kesavadasapuram - Palayam | 5.69 5.93 11.52 |
|   Kesavadasapuram - Kesavadasapuram | 6.87 7.49 3.97 |

Another way to assess the effectiveness of the model is by visual assessment of predicted and actual travel times. Figure displays below shows the actual and predicted average travel times for both models for three stretches. It was evident from the graphs that estimated model was effective in predicting the travel times on the selected road.
SUMMARY & CONCLUSION

A travel time survey was conducted and travel time taken by Public vehicles and Private cars along each link in the study stretch was estimated. Segmentation of the study route was done based on traffic factors, geometric factors and road inventory data obtained from NATPAC. Bus travel time and car travel time for three stretches were modeled using SPSS. Independent variables that included in the model were average travel time, dwell time and volume. Linear regression analysis yielded reasonable parameter estimates for three stretches. In the models, volume and dwell time gives a positive effect to travel time of vehicles. Volume and dwell time have an additional impact on flow. Increase in volume obviously causes an increase in travel time during peak hour. \( R^2 \) Statistics for all the stretches were found to be relevant and t-statistics for all parameters were found to be significant. Most of the t - Statistics are found to be more than that of t - value obtained from t- tables. \( R^2 \) value for Sreekaryam - kesavadasapuram stretch was found to be more compared to other stretches. From the models it was found out that, Bus travel time depends on car travel time and volume. For all three stretches, it was found out that car travel time depends on bus travel time, volume of traffic, and dwell time. Validation of travel time models was carried out using statistical method. MAPE (Mean Absolute Percentage Error) was the statistical measure used to test the model performance. MAPE values of all the stretches were found to be in between 0 and 20 and model was proved as fit to find future variation in travel time of vehicles. Effectiveness of the models was assessed by visual assessment of predicted and actual travel times. It was evident from the graphs that estimated models are also effective at predicting the travel time on the selected stretches.

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