QUANTIFYING ROAD USER COSTS WITH HETEROGENEOUS VALUE OF MOTORISTS' TRAVEL TIME

A Thesis

by

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ABSTRACT

The state transportation agencies (STAs) in the United States are mandated by federal rule to carry out work-zone impact assessment for highway rehabilitation projects. The work zone impact assessment requires calculating road user costs (RUCs) which is the sum of vehicle operating costs, accident costs, and value of time (VOT). The term ‘value of time’ refers to monetary equivalent of travel time wasted due to rehabilitation projects. In current practice, STAs assume VOT as homogeneous within their respective states. This leads to inaccurate RUCs calculations and poses many misapplications.

Research has found that VOT is influenced by socio-demographic variables which vary within the states. But there is a lack of framework to evaluate the extent to which these factors affect value of time. The major objective of this research is to develop and validate a model that predicts value of time heterogeneously.

The data were collected to cover 20 major cities in California. The state of California was chosen for this study because most highway rehabilitation projects are carried out there. The data sources included the United States Census Bureau, the California Department of Transportation (Caltrans), and the Bureau of Labor Statistics. With these data, a predictive model was developed using multiple linear regression analysis. Lastly, the model was validated using PRESS statistic. The results reveal that

age, annual average daily traffic, and effective hourly income were the most significant factors influencing value of time.

This study developed a model which will help Caltrans in calculating value of time heterogeneously and therefore, improve the accuracy of RUCs calculations. Moreover, this research will serve as a guideline for other STAs to develop models for respective states. Therefore, this model has a potential to greatly improve the accuracy of value of time and therefore, RUCs.

The future research should focus on the identified factors, especially cost-of-living index and annual average daily traffic. Further research is required to account for heterogeneity due to other factors such as vehicle occupancy, frequency of travel, and educational qualifications.

DEDICATION

To the most special people in my life

Madhu Tiwari

Manoj Tiwari

Shruti Tiwari

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Finally, I am grateful to my parents for infinite love, support and encouragement to work harder. I wish them the best for their good health and spirits. I dedicate my Master of Science degree to them.

NOMENCLATURE

AADT	Annual Average Daily Traffic
BLS	Bureau of Labor Statistics
Caltrans	California Department of Transportation
COLI	Cost of Living Index
EHHI	Effective Hourly Household Income
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
MDOT	Michigan Department of Transportation
MAHI	Median Annual Household Income
MHHI	Median Hourly Household Income
ODOT	Oregon Department of Transportation
RP	Revealed Preference
RUC	Road User Cost
SP	Stated Preference
STAs	State Transportation Agencies
TxDOT	Texas Department of Transportation
USCB	United States Census Bureau
USDOT	United States Department of Transportation
VOT	Value of Time

VTT	Value of Travel Time
VTTS	Value of Travel Time Savings
WTP	Willingness-to-pay

DEFINITION OF TERMS

Value of Time	The monetary equivalent of travel time wasted as a result of rehabilitation work
Cost-of -living Index	A composite index calculated from grocery costs, housing costs, utilities expenses, transportation costs, and miscellaneous goods and services
Road User Costs	The Costs incurred to traveling public due to rehabilitation projects in the form extra fuel, accident costs and lost time

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1 INTRODUCTION

1.1 Current State of Highway Infrastructure in the United States

Most state highways in the United States were built during the construction boom from 1950s to 1980s with a 20-year design life (Kim 2012; Lee and Ibbs 2005). As a result, a significant portion of highway infrastructure has already exceeded its design life. The condition of highways has badly deteriorated due to wear and tear, increasing congestion, increase in freight transportation, delayed maintenance and repair, and increasing construction costs (Salem et al. 2013).

An estimated 24% of the country's major metropolitan roads, interstates, freeways, and other major routes have substandard pavement condition and provide a rough ride to the travelers (TRIP 2010). The highway traffic due to passenger cars and freight transportation is expected to increase which will further deteriorate the infrastructure and create safety problems for motorists (Salem et al. 2013).

In order to rebuild the deteriorated highway infrastructure in a viable way, the State Transportation Agencies (STAs) have shifted focus from construction of new highways to rehabilitation of existing ones (Herbsman and Ellis 1995; Herbsman and Glagola 1998). The rehabilitation work is often carried out using full or partial lane-closure techniques, which causes significant delays to traveling public (Lee and Ibbs 2005). Moreover, delays in freight transportation has a potential to affect many businesses (Salem et al. 2013).

In addition to the traffic delays, lane closures techniques used during rehabilitation projects pose several safety problems. Therefore, STAs have to overcome the challenge to complete the projects on time while minimizing their impact on traveling public (Salem et al. 2013). To ensure that rehabilitation projects are carried out in a safe and efficient way, Federal Highway Administration (FHWA) passed a new rule in October 2007. The new rule was aimed at providing the STAs with a decision-making framework to evaluate safety and mobility impacts of work zones. As a part of this rule, STAs were also required to develop procedures for work zone impact analysis (Sankar et al. 2006). The work zone impact is evaluated in terms of road user costs (RUCs). RUCs are the costs incurred by traveling public due to rehabilitation projects in progress (Salem et al. 2013). A critical component of RUCs is the value of time (VOT). VOT refers to the monetary equivalent of time wasted as a result of rehabilitation projects (Daniels et al. 1999). It is usually measured in terms of 'dollars per hour ($/hr)'. VOT is a critical parameter which forms the basis of assessing work zone impact due to highway rehabilitation projects.

1.2 Calculating Value of Time as Heterogeneously

STAs are often faced with challenges to accurately calculate VOT in terms of dollars per hour. In current practice, STAs assume VOT to be homogeneous for all cities within their respective states. For instance, Texas uses the same VOT for all cities including Houston, Austin, San Antonio, Dallas, etc. This leads to inaccurate RUCs calculations and poses many misapplications. Research has shown that factors, on which value of time depends, may vary within a state. Therefore, value of time must be treated as heterogeneous.

Therefore, it is important to study various factors that influence value of time. Moreover, a framework is required to integrate the identified factors into one model to calculate VOT heterogeneously.

2 RESEARCH SCOPE AND SIGNIFICANCE

2.1 Gaps in Existing Knowledge

2.1.1 Factors Affecting Value of Time

Several VOT studies have identified household income as a major factor affecting value of time. STAs calculate VOT using hourly household incomes. However, some survey studies have found that there may be factors other than hourly household income, which influence motorists' willingness-to-pay.

The variables such as vehicle occupancy, purpose of trip, and age are important factors of express-lane use, which indicates that these variables may affect motorists' value of time (Li 2001). A commuter survey study revealed that household income, age, and time of travel affect motorists' value of time (Small et al. 2005). United States Department of Transportation (USDOT) identifies six possible determinants of VOT, namely: trip purpose; personal characteristics such as age, sex, education, and employment; hourly income; mode of travel such as public transport or private vehicle; and comfort level associated with travel (USDOT 2011). However, there is no such study that considers the impact of factors such as cost-of-living index and annual average daily traffic (AADT) on value of time.

2.1.2 Lack of Systematic Model to Calculate Value of Time Heterogeneously

In current practice, STAs assume VOT to be homogeneous across their respective states. For instance, Caltrans currently adopts $12.50 per hour value of time (Caltrans 2012). Therefore, Caltrans assumes VOT to be same for every single city in California, including San Francisco, San Jose, San Diego, Los Angeles, etc., despite the fact that socio-demographic and traffic factors are different for each city. This leads to inaccurate RUCs calculations and poses many misapplications.

In the UK, value of time is assumed to be homogeneous, despite an acceptance that VOT varies with socio-demographic and economic characteristics (Mackie et al. 2003). Similarly, STAs, despite acknowledging the fact that value of time depends on several factors, assume VOT as homogeneous.

The STAs lack a systematic model to accurately calculate VOT heterogeneously based on various factors. After conducting a comprehensive literature review, it was found that although many studies have examined the influence of different factors on value of time, no systematic model has been developed to quantify the extent to which these factors influence value of time.

2.2 Research Objectives

Determination of more accurate and realistic VOT is critical to the quantification of RUCs. Currently, STAs treat VOT as homogeneous which leads to inaccurate RUCs calculations. Although STAs realize that there may be various factors affecting the value of time, they lack a systematic framework to calculate value of time heterogeneously. To overcome this problem, first a thorough review of literature was conducted to identify factors that affect the value of time. After identifying factors that may possibly affect value of time, a statistical analysis was carried out to find if value of time is influenced by any of these factors.

The primary objective of this research was to develop an accurate and reliable model to quantify value of time heterogeneously. To achieve this objective, this study had the following major goals:

- To identify critical factors that affect user preferences and hence affect value of time
- To investigate the influence of identified factors on value of time
- To develop a quantifying model to calculate value of time heterogeneously

2.3 Research Methodology and Hypothesis

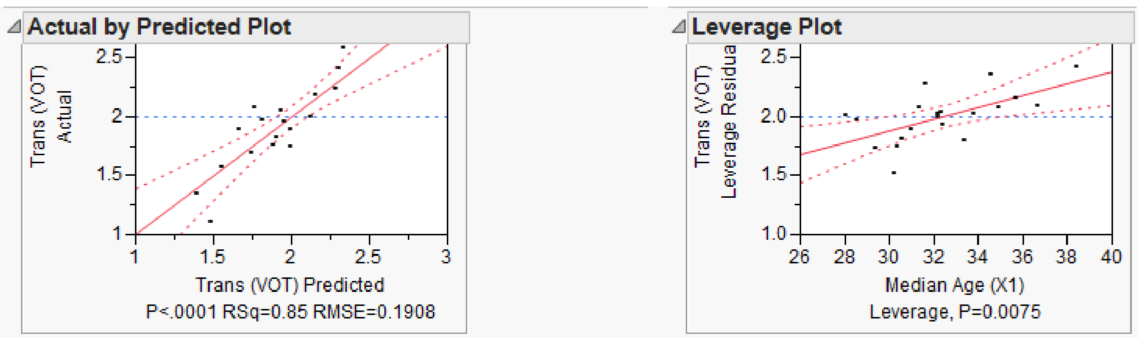
2.3.1 Tasks to Achieve Research Objectives

This research effort aims to quantify value of time in terms of indentified factors. Analytical modeling was one of the research methods proposed by Ansari et al. (2006). In an analytical modeling method, a model is developed based on different parameters, which in this case are the identified factors.

To achieve the desired objectives, a thorough literature review was carried out to identify factors that affect user preferences and hence value of time. After identifying the factors, reliable sources for data collection were identified for 20 major cities in the state of California. The data sources primarily included government sources such as California Department of Transportation, Bureau of Labor Statistics, and United States Census Bureau. With the available data, a multiple linear regression analysis was performed using statistics analysis software JMP10. Figure 1 shows a sample JMP10 output. First, statistical assumptions were tested. Then, regression analysis was performed using backward elimination method to reject insignificant factors from analysis. Finally, to validate the proposed model PRESS statistic was used. The following steps present an outline of procedure mentioned above:

- Identified factors affecting value of time based on existing literature
- Collected reliable data for value of time and the identified factors for 20 major cities in the state of California
- Tested normality of data to ensure unbiased analysis

- Examined the relationship between value of time and identified factors using scatter plots
- Ensured that identified factors are not collinear
- Conducted multiple linear regression analysis to develop a VOT prediction model
- Validated the model using PRESS statistic



Summary of Fit

RSquare	0.850265
RSquare Adj	0.810335
Root Mean Square Error	0.19078
Mean of Response	2.000531
Observations (or Sum Wgts)	20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	3.1001727	0.775043	21.2942
Error	15	0.5459544	0.036397	**Prob > F**
C. Total	19	3.6461271		<.0001*

Figure 1: Sample JMP10 output for regression analysis

2.3.2 Statistical Analysis

For generating a reliable prediction model, a stepwise statistical analysis was carried out using JMP10. The data for this study were collected from reliable sources such as the United States Census Bureau, the Bureau of Labor Statistics, and the Traffic Data Branch of California Department of Transportation (Caltrans). The following statistical procedures were implemented with the data obtained:

1. Data stratification

   The raw data were converted into relevant data which were then used for regression analysis. The annual income data were from 2011. Therefore, it should be converted into hourly 2013 values.

2. Descriptive statistics and scatter plots

   Descriptive statistics consisted of basic information about data such as mean, standard deviation, units, designation, and variance. Scatter plots gave an idea of the variation of value of time (VOT) with independent variables.

3. Normality test

   For a regression analysis, the data should be normally distributed. To test normality, Shapiro-Wilk test was performed and Q-Q plots were looked at.

4. Data transformation

   The data were found to be not normally distributed; they were transformed into normally distributed values. Box-Cox transformation was used for this purpose.

5. Heteroscedasticity and independent variables

   The transformed data must not have any heteroscedasticity, meaning that residuals must be randomly distributed. Moreover, the X_i variables used in the study must be independent of each other. Therefore, correlation and heteroscedasticity tests were performed.

6. Regression analysis using backward elimination

   Once all the assumptions were tested, regression analysis was performed in a number of steps. In each step, an insignificant variable was eliminated and regression analysis was performed again. This process is known as the method of backward elimination.

7. ANOVA test

   The significance of final model was tested using ANOVA test.

8. Validity check

   Validity of the model was checked using adjusted R-square values and PRESS Statistic.

9. Meaning of coefficients

   Once the validity of model was tested, meaning of each coefficient (β_i) was discussed.

2.3.3 Hypothesis

The purpose of this study was to test the validity of the following research hypothesis:

- If it is possible to predict value of time (VOT) in terms of identified factors and VOT

Following model was used to test this hypothesis:

Model: $$\mathrm{VOT} = \beta_0 + \beta_1 * \mathrm{AGE} + \beta_2 * \mathrm{AADT} + \beta_3 * \mathrm{EHI} + \beta_4 * \mathrm{SIZE}$$

AGE = Median Age (years)

AADT = Annual Average Daily Traffic (vehicles/hour) (in thousands)

EHI = Effective Hourly Income ($/hr)

SIZE = Size of City (square miles)

VOT = Value of Time ($/hr)

The factors were identified based on the literature review Brownstone et al. (2003), Small et al. (2005), and Kato et al. (2011) concluded that motorists aged more than 30 years value their time much higher than those in their 20s. Therefore, median age was identified as a factor.

USDOT (2011) pointed out a possible heterogeneity in VOT among travelers to reduce travel time because of conditions which cause discomfort which may be due to heavy traffic. Therefore, Annual Average Daily Traffic (AADT) was identified as a factor.

Börjesson et al. (2012), and Santos and Bhakar (2006) concluded that there exists a positive relationship between income and value of time. Therefore, effective hourly income was identified as one of the factors.

Axhausen et al. (2006) found out that there exists a significant relationship between trip distance and value of time. Size of city in terms of land area was considered as a measure of trip distance because larger land area would mean larger distances. Therefore, size of city was considered as one of the factors.

This model confirmed the relationship between value of time (VOT) and some of the critical factors which were identified in the literature review.

2.4 Research Assumptions

- The inflation rates in the state of California varied from 0.7% to 2.4% over the last 4 years (Table 1). For purpose of this study, 2% inflation rate is assumed (BLS 2012).

Table 1: Inflation rates for California

Year	Inflation (%)
2009-10	0.7
2010-11	1.7
2011-12	2.4
2012-13	2.2

- For calculating hourly wage, annual income is divided by 2080 hours as per USDOT guidelines (USDOT 2011).
- USDOT guidelines recommend using 50% of hourly household income as the value of time (VOT) for 'on-the-clock' business travel and for within-the-city local travel (USDOT 2011).
- The cost-of-living index data is for year 2010. It is assumed that it has remained unchanged through 2013 (USCB 2012).
- Annual average daily traffic (AADT) data is for year 2011. It is assumed that it has remained unchanged through 2013 (TDB 2013).

2.5 Research Limitations

- This research is limited only to passenger cars; public transportation, trucks, and locomotives are out of scope
- The model does not consider heterogeneity due to vehicle occupancy which may vary from city to city
- This study is limited to the state of California
- This study is limited for “on-the-clock” business travel because maximum traffic delays occur during peak hours
- The study is limited to local within-the-city travel
- The traffic data is obtained from the Traffic Data Branch of California Department of Transportation (Caltrans). However, imperfections in traffic data may have influenced the result of this study.

2.6 Significance of Study

To carry out work zone impact analysis, STAs must be able to calculate value of time as the baseline of the RUCs. Currently, STAs use homogeneous VOT for all cities in their respective states. This leads to inaccurate calculations of RUCs and poses many misapplications. STAs lack a reliable and accurate framework to calculate VOT heterogeneously.

This study attempted to develop a more accurate and realistic framework for value of time by considering various factors such as age, annual average daily traffic, and effective hourly income. The accuracy of model was further enhanced by incorporating cost-of-living index.

Road user costs (RUCs) serve as the baseline parameter of many crucial planning and construction activities including incentive/disincentive provisions, A+B contracting, lane closure schemes, construction windows, etc. Inaccurate calculation of RUCs contributes to many misapplications that generate low benefit-cost ratios to the traveling public. The results from this study will help STAs determine more accurate and realistic RUCs so that they could plan better for the given project while also minimizing traffic inconvenience to the traveling public during lane closures.

Moreover, evaluation of accurate value of time will also make road pricing calculations more accurate. For calculating accurate toll prices, STAs must know the tolls public is willing to pay. For example, if tolls are overvalued, express lanes would remain underused. On the other hand, if tolls are undervalued, express lanes would be overused and travel time would increase. Therefore, VOT can be used to calculate tolls in such a way that the balance of traffic in general purpose lanes and express lanes is maintained.

3 LITERATURE REVIEW

3.1 Highway Construction Trends in the United States

Most state highways in the United States built during the construction boom between 1950's and 1980's, have exceeded their 20-year design life (Kim 2013; Lee and Ibbs 2005). Due to recent economic downturn, the Federal Government opted for economically efficient ways to rebuild highway infrastructure (Kim 2013). As a result the focus shifted from construction of brand new highways to rehabilitating and repairing the existing ones (Herbsman and Ellis 1995; Herbsman and Glagola 1998). Numerous rehabilitation projects have been undertaken across various cities in the United States. The rehabilitation work is often carried out by partial or full lane closure techniques which results in reduced operational capacity of roadways. Consequently, traveling public is affected in terms of traffic delays, increased road user costs, air pollution, and safety (Sankar et al. 2006).

To minimize impact of rehabilitation projects and to ensure safety of commuters, FHWA passed a new rule mandating STAs to perform work zone impact analysis for highway rehabilitation projects which were undertaken after October 2007. This impact is calculated in terms of road user costs (RUCs), which refers to costs incurred by the traveling public due to rehabilitation work (Sankar et al. 2006).

3.2 Road User Costs in Highway Rehabilitation Projects

STAs are required to carry out work zone impact analysis for highway rehabilitation projects to ensure minimum impact on traveling public. That work zone impact is evaluated in terms of road user costs (RUCs) (Salem et al. 2013). RUCs are defined as the costs incurred by road users due to highway rehabilitation projects (Daniels et al. 1999; Lewis 1999). RUCs may be incurred due to additional travel time costs due to detours and highway congestion, accident costs due to crashes and accidents in work zones, and operating costs due to additional use of fuel, oil, and maintenance (Reigle and Zaniewski 2002).

RUCs are a function of the timing, duration, frequency, scope, characteristics of the traffic affected, and the dollar cost rates assigned to vehicle operations and delays. By understanding major factors affecting RUCs, STAs can minimize the impact of future rehabilitation projects on highway travelers. RUCs play an important role in calculating equivalent money lost due to rehabilitation work. Although RUCs are not direct costs to STAs, they do directly affect the traveling public (NJDOT 2001).

The rehabilitation work is carried out using full or partial lane closure of pavements that disrupts the normal traffic flow. Therefore, rehabilitation projects have significant contribution to RUCs (Salem et al. 2013). A major component of RUCs is costs incurred due to delays. These delay costs can be accumulated due to long queues near work zones, frequent deceleration, reduced car speed to ensure safety, and time required to accelerate to normal speeds (Jiang 1999).

The RUCs are influenced by several factors such as travel time which governs traffic demand, highway capacity, duration of rehabilitation work, traffic restrictions near work zones, and availability of detours (Walls III and Smith 1998). In other words, RUCs consist of three basic components: vehicle operating cost, accident cost, and value of time (Daniels et al. 1999; Walls III and Smith 1998).

Vehicle operating costs are costs incurred by the user due to frequent slowing, idling and stopping in the work zone. This leads to more fuel and oil being used, and subsequently increased maintenance costs. Most STAs do not consider slowing and stopping costs while calculating vehicle operating costs. Instead, only idling costs are used by STAs to calculate vehicle operating costs (Salem et al. 2013). When rehabilitation projects are in progress, vehicles experience increased wear and tear and decreased fuel efficiency (Trzcinski and Corotis 2007). This leads to increased maintenance costs.

American Association of State Highway and Transportation Officials (AASHTO) pointed out that there is an increased probability of accidents due to lane closures and detouring during rehabilitation projects (Trzcinski and Corotis 2007). Vehicle accident costs refer to costs incurred due to property damage in accidents (Daniels et al. 1999). Crash or accident costs are a function of the crash rate for the work zones. Crash rates are typically specified as crashes per 100 million miles of travel (100 M VMT) (NJDOT 2001).

The RUCs are the sum of the costs accrued on account of delay in the work zone and additional vehicle operating costs. The essential components of work zone user costs include cost of delay due to queue, cost of delay while going through work zone at reduced speed, cost of delay due to speed change cycles, additional operating cost of speed change cycle, vehicle running cost (Salem et al. 2013).

Value of time refers to monetary value of motorists' saved or wasted time (Choi 2008), which may affect their work, leisure activities, family time, etc. In other words, time spent while traveling in a vehicle is a resource with economic value. The monetary value of travel time is based on the concept that time spent traveling otherwise would have been spent productively, whether for remunerative work or recreation (Mallela and Sadasivam 2011).

The primary focus of this study is the third component of road user costs, i.e. value of time. It is discussed at length in the following sections.

3.3 Value of Time

3.3.1 Definition

The component of value of time (VOT) is calculated by the STAs while calculating RUCs. The value of time is incurred by highway users due to delays caused by queues near work zone, delays caused due to reduced speed, delays caused due to frequent slowing down and accelerating cycles, and delays caused due to rerouting or detours (Salem et al. 2013).

VOT can be defined as a motorists' willingness-to-pay to reduce an hour of travel time (Calfee and Winston 1998; Kang and Stockton 2008; Miller 1989; Small and Yan 2001). Kang and Stockton (2008) quantified VOT, as the amount of toll money that travelers are willing to pay in exchange for the reduced travel time. The United States Department of Transportation (USDOT) defines the VOT as the monetary value of travel time savings (USDOT 2011). VOT is usually measured in terms of dollars per hour of motorists' time saved or lost. The term 'value of time' is often used interchangeably with 'value of travel time savings (VTTS)' (Small et al. 2005).

3.3.2 Quantifying Value of Time

Researchers have used several methods to quantify value of time. One of the most common methods has been survey-based stated preferences (SP) approach. The survey data were collected over a period of months from a major metropolitan area. In a SP approach, respondents are asked to state their preferences from a given hypothetical set of scenarios. These scenarios may include unique combinations of toll charges, time saved, time of travel, etc. SP data contain rankings of detailed information about several scenarios (Calfee et al. 2001). The respondents then rank the scenarios from least acceptable to most acceptable. The probability of each scenario is calculated and value of time is determined.

Calfee and Winston (1998) used survey-based SP approach to calculated commuters' willingness-to-pay using hypothetical scenarios consisting of toll charges, time saved, how the toll revenue was used, and whether trucks were allowed on the road or not. The respondents ordered several scenarios that described elements such as congested and uncongested travel time and the travel cost. The value of time was found out to be 19 percent of median household income.

A similar SP analysis was carried out by Calfee et al. (2001), in which value of time was calculated by asking respondents “acceptability” of each scenario on a ten-point scale. A value of time study in the UK was based on SP approach and performed meta-analysis to evaluate value of time (Mackie et al. 2003).

Small et al. (2005) used an innovative approach to calculate VOT. The study combined stated preference (SP) data from hypothetical situations as well as revealed preferences (RP) data from actual choices. In the RP data, respondents reported their first choice from an existing set of alternatives, unlike SP data in which respondent rank their preferences. There is always a doubt associated with stated preferences which are hypothetical in nature, as they may not be applicable to real-life choices. The differences between hypothetical and real choices can be evaluated by combining RP and SP approaches in one study (Small et al. 2005).

A study by Fosgerau (2006) was also based on stated choice experiment to study the effect of socio-economic and situational variables on value of time. A study by Axhausen et al. (2006) also used SP survey design and evaluating effect of socio-demographic factors on value of time.

3.3.3 Heterogeneity of Value of Time

Small and Yan (2001) pointed out that measuring the value of time heterogeneously is important in evaluating congestion policies, and improves the accuracy by offering differential prices. Their model used the concept of heterogeneity in user preferences to evaluate preferences of using express toll lanes.

De Palma and Lindsey (2004) noted that motorists vary with respect to incomes, and socio-economic characteristics. The study concluded that accounting for the heterogeneity due to time of day, and vehicle occupancy, would make road pricing policies more accurate.

Road-pricing strategies such as tolls are often based on motorists' value of time. Pricing strategies adopted by STAs are often based on the assumption that all travelers are homogeneous in terms of value of time (VOT). This assumption does not consider the differences in travelers' VOT and thus, fails to provide accurate road user cost values. Variables such as time of day, travel cost, travel distance, and household income, have been found to influence VOT (Jang and Chung 2010).

Abou-Zeid et al. (2011) conveyed the fact that a high level of heterogeneity for the VOT among travelers exists, which can be due to income, trip purpose, and mode of travel.

A thorough literature review is required to find out which factors determine heterogeneity of value of time. Based on literature, some factors have been identified.

3.3.4 Factors Affecting Value of Time

Some studies have shown that though hourly wage is a significant factor, it is not the only factor affecting value of time. Several factors have been identified apart from hourly income, which would better explain motorists' value of time. Socio-demographic variables such as age, trip distance, persons per household and average daily traffic, may affect value of time.

3.3.4.1 Age

Some studies have shown different values of time across different age groups. Brownstone et al. (2003) found out that motorists from ages 35 to 45 valued time much higher than those in late 20s and early 30s.

Small et al. (2005) studied variation of motorists' willingness-to-pay with socio-demographic factors and found that motorists aged between 30 to 50 years, were willing to pay more than the motorists aged less than 30 years. Similarly, Fosgerau (2006) found out using a stated choice experiment that age had significant dependence on value of time. Kato et al. (2011) also used a stated choice model to conclude that motorists aged in their 20s were willing to pay less that those aged higher.

Motorists' preferences may vary based on socio-economic and demographic variables such as age, sex, education, comfort and employment. (USDOT 2011).

3.3.4.2 Comfort

USDOT points out that there is a possibility of variation in VOT among travelers to reduce time because of conditions which cause discomfort. This discomfort may be due to heavy congestion, too much exposure, and seating for long time. In such situations, motorists' with same set of socio-demographic characteristics may tend to vary in willingness to pay due to different comfort levels (USDOT 2011). Therefore, regular exposure to heavy traffic may incline motorists to pay extra to get rid of discomfort.

3.3.4.3 Trip Distance

Small et al. (2005) found no significant relation between trip distance and value of time. However, USDOT (2011) points out that value of time may be affected by trip distance due to limited time availability for longer distances. Axhausen et al. (2006) studied the effect of socio-demographic characteristics on VOT and reported significant relationship between value of time and trip distance. Similar results were obtained by Mackie et al. (2003).

3.3.4.4 Income

Almost all the studies report that VOT is directly proportional to income. Studies on VOT often express it in terms of hourly income. In practice, STAs also express VOT in terms of total hourly wage. Results from various studies have indicated that relationship between value of time and income has remained unchanged over time (Börjesson et al. 2012). USDOT recommends using 50% of hourly household income as the value of time (USDOT 2011). Household income affects the value of time significantly.

Santos and Bhakar (2006) stated that income is one of the recognized factors affecting value of time. Whereas, Fosgerau (2006) concluded that personal income is a significant determinant to motorists' willingness to pay. The study analyzed value of time for different income slabs and found out that the two variables are directly proportional to each other. That is, motorists with higher incomes were willing to pay more as compared to those with lower incomes.

Brownstone et al. (2003) studied the pattern of motorists' willingness to pay using revealed preferences (RP) data. Income was found to be a significant determinant of willingness to pay.

STAs such as Oregon Department of Transportation (ODOT), Michigan Department of Transportation (MDOT), and Texas Department of Transportation (TxDOT) calculate VOT using per-capita hourly wages (MDOT 2011; ODOT 2011; TxDOT 2011). TXDOT evaluates value of time on the basis of hourly income. The "value of time" is adjusted each year based on consumer price index (CPI) of the previous year (TxDOT 2011).

Small et al. (2005) found out that motorists with household income of less than $60,000 per annum were willing to pay much less compared to motorists with income

$60,000-$1,00,000 per annum. Jang and Chung (2010) in their study identified variables such as travel time, trip distance, household income and travel cost, in determining value of time.

Small (2002) pointed out that value of time in major cities varies from 20 to 100 percent of the hourly household income. An average value of 50 percent of hourly household wage can be assumed to be reasonable. Miller (1989) carried out a survey based study and found the value of time equal to 60 percent of hourly household income. While, Calfee and Winston (1998) found out value of time equal to 20 percent of hourly household income.

3.3.4.5 Trip Purpose

For quantifying value of time, it is important to note that heterogeneity exists depending on trip purpose. For example, a motorist might be willing to pay $20/hr when he is wants to get to work on time. On the other hand, the same person might be willing to pay only $10/hr when he is making a leisure trip.

Trip purpose can depend on: 'on-the-clock' business travel for which motorist is getting paid, and 'off-the-clock' personal or leisure travel for which no income is generated. Research has revealed that VOT for personal or leisure travel is lower than VOT for business travel (Santos and Bhakar 2006; USDOT 2011).

Devarasetty et al. (2012) and Brownstone et al. (2003) noted that road users were willing to pay different amounts for business trips and leisure trips. Peak hours are generally associated with business purpose trips. Therefore, road users value their travel time more during peak hours than non-peak hours. A value of time study carried out in Japan revealed that value of time was found to be higher from 8am-10am in the morning and 6pm-8pm in the evening (Kato et al. 2011).

3.3.4.6 Cost-of-Living Index

According to Bureau of Labor Statistics, cost-of-living index (COLI) measures differences in the price of goods and services, and allows for substitutions to other items as price change. It can measure changes over time in the amount that consumers need to spend to reach a certain utility level or standard of living. COLI can be used for city-to-city comparisons (BLS 2012).

COLI is basically a composite index which takes into account grocery costs (13%), housing costs (29%), utilities expenses (10%), transportation costs (12%), healthcare costs (4%), and, miscellaneous goods and services (32%). The United States index average is equal to 100% and each index is expressed in terms of a percent of the country average. Each category is represented by different weights which are based on recommendation of Bureau of Labor Statistics (USCB 2012).

Several studies have been carried out for VOT. However, this is the first time that a VOT study analyzes the effect of COLI on VOT. The reason for studying COLI is that it directly affects the spending capacity of individuals. For example, consider two cities with same median household incomes, but different COLI. It is fair to say that the residents of the more expensive city would probably save less and therefore, may have less spending power as compared to the cheaper city with same income levels.

Renwick (2011) captures that using just two housing cost estimates for each state can misrepresent the cost of living in states where there are multiple metropolitan areas with large differences in the cost of living. Similarly, it can be concluded that, not accounting for cost-of-living index for calculating value of time can misrepresent VOT in states where there are multiple cities with different cost-of-living indexes.

4 DATA COLLECTION AND STRATIFICATION

4.1 Introduction

The focus of this research study was limited to the state of California. For the purpose of this study, 20 most populous cities in California were selected and data related to each of these cities were collected. The data consisted of socio-demographic data and traffic data. However, Fontana which is the 20^{th} most populated city in California was excluded because of insufficient traffic data. Moreno Valley, the 21^{st} most populated city in California, replaced Fontana in this study.

The data for this study were collected from sources such as United States Census Bureau, Bureau of Labor Statistics and California Department of Transportation. These sources are discussed in following sections:

4.1.1 United States Census Bureau

US Census Bureau is a part of U.S. Department of Commerce. The organization collects data such as population & housing census, economic census, census of governments, American community survey, demographic surveys, and economic indicators. Census data affect the funding allocation for communities for neighborhood improvements, public health, education and transportation (USCB 2012). This study used socio-demographic factors from US Census website. These socio-demographic factors included age, cost of living index, median annual household income, and per capita annual income.

4.1.2 California Department of Transportation (Caltrans)

California Department of Transportation is the state transportation agency (STA) which oversees more than 50,000 miles of highway and freeway lanes in California (Caltrans 2012).

The Traffic Data Branch of Caltrans is responsible for dissemination of historical volume and speed data. The Traffic Data Branch collects data each year for trucks and passenger cars for various roadways in major cities across the state. The data usually consist of the annual average daily traffic (AADT) volumes on selected highways located in various city areas across the state of California (TDB 2013).

4.1.3 Bureau of Labor Statistics (BLS)

The Bureau of Labor Statistics (BLS) is an independent statistical agency in operation since 1884. The agency is a part of U.S. Department of Labor, which is a federal agency responsible for measuring market activities, working conditions, and price changes in the country. The data collected by BLS help in public and private decision-making (BLS 2012).

For this study, inflation values for state of California were collected from BLS website. It was observed that inflation rate varied from 0.7% to 2.4%. Therefore, 2% inflation rate was assumed in this study.

4.2 Factors Identified

4.2.1 Effective Hourly Income

As discussed in the literature review section, income is one of the most influential factors affecting the motorists' value of time. However, most studies do not consider the fact that different cities have different costs of living which, thereby, impacts the motorists' willingness-to-pay. For example, two motorists with same hourly incomes but different costs of living will have different values of time.

For the purpose of this study, a new term was proposed: "effective hourly income (EHI)". It is defined as the 'effective income' of motorists while taking into consideration their living expenses. It depends on 'median hourly household income' and 'cost-of-living index'. Both these factors are discussed in detail in the following sections.

4.2.1.1 Median Hourly Household Income

Research has shown that value of time is often proportional to their hourly income. It is interesting to note that some studies define per-capita hourly income as a factor affecting value of time while some studies define hourly household income as one of the factors.

This study identified median hourly household income (MHHI) as a factor instead of per capita income due to the assumption that all the members of a family are expected to have almost equal spending capacity, irrespective of their individual incomes. In USDOT's terms, incomes are spread over several family members, including non-earners (USDOT 2011). Therefore, median hourly household income (MHHI) was used in this study.

Median hourly household income for a city was computed as follows:

$$\text{Median Hourly Household Income (MHHI)} = \begin{cases} W^{\left(\frac{n+1}{2}\right)} & \textit{if n is odd} \\ \dfrac{W^{\left(\frac{n}{2}\right)} + W^{\left(\frac{n+1}{2}\right)}}{2} & \textit{if n is even} \end{cases}$$

Where W = Median hourly household income

N = sample size, which reflects the population of city

While calculating median income, the effect of few outliers was minimized. Therefore, median income is more robust than mean income. The data were extracted from United States Census Bureau website. All income data were adjusted to 2011 dollars. However, median annual household income (MAHI) data were available for each city. Moreover, the data were expressed in 2011 dollars. To convert the data into inflation adjusted hourly figures, two steps were applied. In the first step, inflation factor was used to adjust annual income figures to 2013 dollars.

$$\text{MAHI}_{2013\text{ dollars}} = (\text{MAHI}_{2011\text{ dollars}}) * (1 + \frac{\text{i}}{100})^2$$

In the second step, the adjusted annual income was divided by a factor of 2080 hours to convert it to hourly income.

$$\mathrm{MHHI}_{2013\ \mathrm{dollars}} = \frac{\mathrm{MAHI}_{2013\ \mathrm{dollars}}}{2080\ \mathrm{hours}}$$

USDOT guidelines recommend that total number of working hours in an year must be assumed as 2080 hours (USDOT 2011).

4.2.1.2 Cost-of-Living Index

The daily expenses incurred by motorists may also affect their value of time. For instance, consider two cities having same median hourly household income but one city has a much higher cost-of-living index than the other. It is fair to say that more expensive city would mean reduced savings, which implies less 'effective income' for motorists to pay for reducing travel time.

Cost-of-living index represents the daily expenses incurred by motorists in the form of grocery costs, housing costs, transportation costs, etc. Therefore, it may affect value of time. Cost-of-living index data were obtained from United States Census website. The data were for year 2010. It was assumed that cost-of-living index was the same for 2013. As discussed in the literature review section, cost-of-living index is a composite index which is expressed in terms of percentage.

4.2.1.3 Quantifying Effective Hourly Income

The term Effective Hourly Income (EHI) is defined as the ‘effective income’ of a motorist obtained by adjusting median household hourly income using cost-of-living index. Effective hourly income is directly proportional to hourly household income. If hourly household income increases assuming constant cost-of-living index, effective hourly income would also increase. On the other hand, effective hourly income is inversely proportional to cost-of-living index. Therefore, if cost-of-living index increases, effective hourly income would decrease because of reduced spending capacity. The term ‘effective hourly income’ is more robust as compared to ‘hourly household income’ as it takes into consideration road users’ daily expenses.

It was calculated for each city by dividing ‘median hourly household income (MHHI)’ by ‘cost of living index (COLI)’. In mathematical terms:

$$\mathrm{EHI}_{2013\ \mathrm{dollars}} = \frac{\mathrm{MHHI}_{2013\ \mathrm{dollars}}}{\mathrm{COLI}}$$

Therefore, hourly income was converted into effective hourly income based on cost-of-living index.

4.2.2 Median Age

Based on the literature review, age was identified as a factor which may affect value of time. Motorists belonging to higher age group may be associated with added responsibility such as children, or other personal things. Therefore, heterogeneity of value of time can be expected due to age. Data for median age of each city were extracted from United States Census Bureau website. The data were for year 2010. However, it was assumed that median age for 2013 is the same as median age for 2010.

4.2.3 Size of City

As discussed in the literature review section, some studies have discussed about trip distance being a factor affecting value of time for motorists. In this study, size of city in terms of city area was considered as a measure of trip distance. As the area of city increases, travel distances are also expected to increase. For each city, data for land area, in terms of squares miles, were extracted from United States Census Bureau website.

4.2.4 Annual Average Daily Traffic (AADT)

Annual average daily traffic is calculated by dividing total traffic volume for a year by 365 days. The traffic counts are adjusted for variations weekdays and weekends, and seasonal changes. This study used 2011 traffic volumes as measured by the Traffic Data Branch of Caltrans. The traffic count was carried out from October 1st through September 30th. The AADT's capture both directions of travel in the count (TDB 2013). It was assumed that AADT has remained the same for last two years.

Literature review discussed the emphasis motorists place on comfort levels. More traffic may lead to less smooth driving experience, which may lead to more fatigue, mentally and physically, which may lead them to pay more. Annual Average daily traffic (AADT) was identified as a possible factor affecting value of time.

Traffic data were collected from Caltrans website. Traffic Data Branch of Caltrans is responsible for collecting this data. AADT data were available for various roadways across different cities across the state of California. For each city, AADT were evaluated by calculating median of AADT values on highways.

4.3 Value of Time (VOT)

As discussed in the literature review, studies have shown that VOT ranges from 20 to 100% of hourly household wage. Florida Department of Transportation (FDOT) sponsored a survey-based value of time study which revealed that motorists valued their travel time equal to 49 percent of their hourly wage based on annual household income (Perk et al. 2011).

Moreover, USDOT guidelines recommend VOT equal to 50% of hourly household income. VOT was assumed to be 50% of median hourly household income based on USDOT guidelines (USDOT 2011) and literature review. Therefore, VOT values used for the purpose of this study are listed in Table 2.

Table 2: Value of time for 20 cities in California

City	Value of Time (VOT) ($/hr)
Los Angeles	14.07
San Diego	15.94
San Jose	20.20
San Francisco	18.24
Fresno	10.86
Sacramento	12.70
Long Beach	13.24
Oakland	12.79
Bakersfield	13.67
Anaheim	14.84
Santa Ana	13.60
Riverside	14.39
Stockton	11.85
Chula Vista	16.39
Fremont	24.64
Irvine	23.16
San Bernardino	10.04
Modesto	12.47
Oxnard	15.05
Moreno Valley	14.20

5 STATISTICAL ANALYSIS

5.1 Descriptive Statistics

The descriptive statistics of the data are shown in Table 3. The dependent variable in this research was value of time ($/hr) designated as VOT. The mean value of VOT was $15.12 per hour with standard deviation, of $3.82 per hour. Median age (AGE) had a mean value of 32.37 years with 3.00 years standard deviation. Annual average daily traffic (AADT) had a mean value of 115.95 (×1000) vehicles per day with 44.85 (×1000) vehicles per day standard deviation. Effective hourly income (EHI) had a mean value of 22.84 $ per hour with 3.91 $ per hour standard deviation. Size of city (SIZE) had a mean value of 103.13 sq. miles with 109.70 sq. miles standard deviation.

Table 3: Descriptive statistics

	Variables	Unit	Designation	Mean	Std. Deviation	N
Dependent variable	Value of Time	$/hr	VOT	15.12	3.82	20
Independent variables	Median Age	Years	AGE	32.37	3.00	20
	Annual Average Daily Traffic	Number of vehicles(×1000)/day	AADT	115.95	44.85	20
	Effective hourly income	$/hr	EHI	22.84	3.91	20
	Size of city	Sq. miles	SIZE	103.13	109.70	20

5.2 Testing Assumptions and Scatter Plots

5.2.1 Testing Normality of Data

To develop a quantifying model for value of time, the first step in statistical analysis is to check for normality of data. Shapiro-Wilk test and Q-Q plots give a measure of normality of data. JMP10 software was used to calculate the p-value. Figure 2 shows the Q-Q plot output obtained from JMP10. The p-value for Shapiro-Wilk test was found out to be 0.0142 (Table 4). Therefore, the data were not normally distributed.

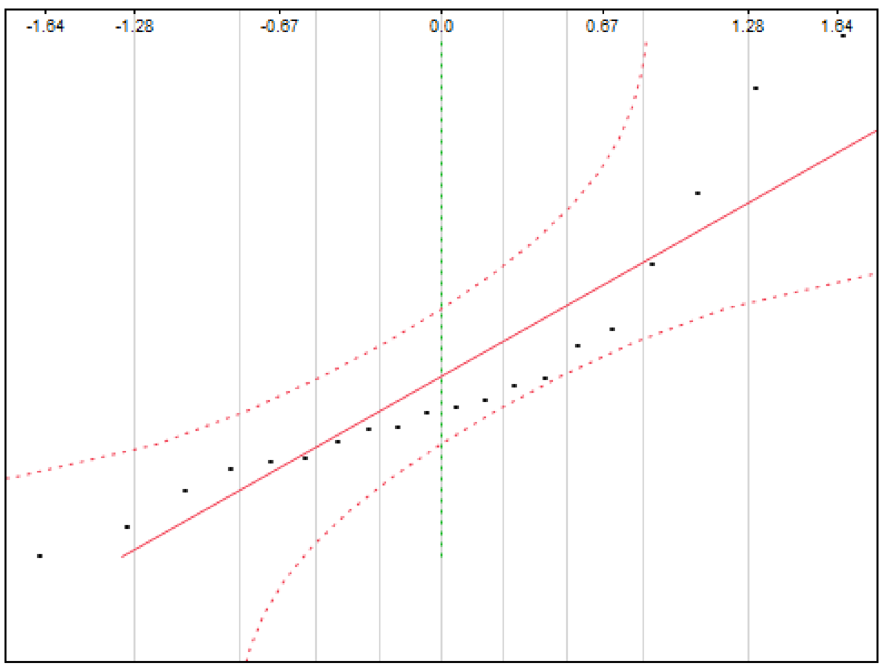


Figure 2: Q-Q plot of data

Table 4: Test for normality of data

Shapiro-Wilk Test	
p-value	0.0142

Since, the data were not normally distributed, it required transformation. Box-Cox transformation is a special class of transformation with the help of which data in this study was transformed. The following log transformation was used to make the data into normal distribution.

$$TRANS\ (VOT) = LOG_e(VOT-7)$$

Upon data transformation, Q-Q plot was obtained as shown in Figure 3. For small sample size, Q-Q plot obtained was satisfactory. Also, the p-value for Shapiro-Wilk test was found to be 0.8250 which was greater than 0.05 (Table 5). Therefore, the data were transformed successfully into normal distribution. Normality problem has been resolved.

Table 5: Test for normality of transformed data

Shapiro-Wilk Test	
p-value	0.8250

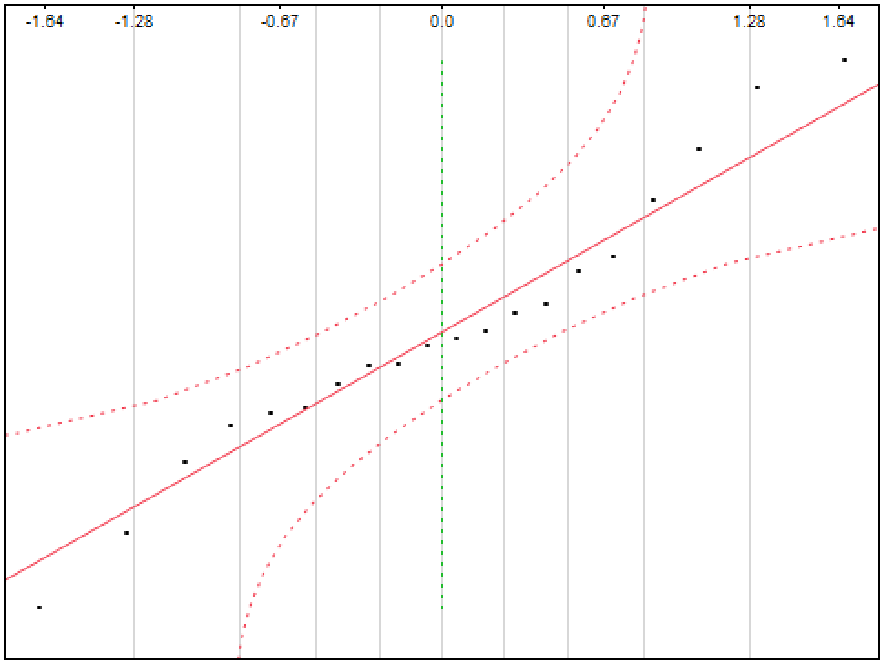


Figure 3: Q-Q plot for transformed data

5.2.2 Independent Variables

For a regression model to be valid, the independent variables should not be correlated to each other. That is, the data must satisfy the independent variables assumption. Therefore, a pairwise correlation analysis was conducted using JMP10. The output is shown in Table 6. It was observed that p-values for all pairwise correlations are greater than 0.05, which suggested that the identified variables were independent. Therefore, the data satisfied the assumption of independent variables.

Table 6: Pairwise correlations to test independent variables

Pairwise correlation of variables		P-value
AADT	AGE	0.0532
SIZE	AGE	0.4832
SIZE	AADT	0.1939
EHI	AGE	0.2991
EHI	AADT	0.8740
EHI	SIZE	0.8767

5.2.3 Presence of Heteroscedasticity

For a multiple regression model, a test for the presence of heteroscedasticity must be conducted. Heteroscedasticity means that modeling errors are correlated and their variances vary with the effects being modeled. Heteroscedasticity should be absent from regression model. It is basically a test of residuals versus predicted value of y or value of time in this case.

Figure 4 shows the output of heteroscedasticity test. It was concluded that the residuals are randomly distributed and no specific pattern was observed. Therefore, the assumption of absence of heteroscedasticity was satisfied.

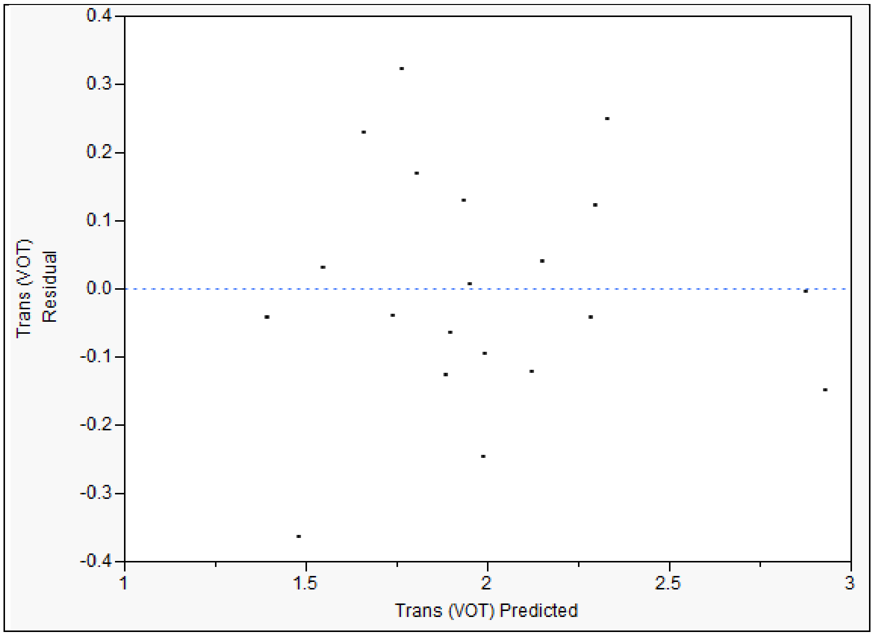


Figure 4: Test for heteroscedasticity

5.2.4 Scatter Plots

Scatter plots were used to test the effect of each independent variable on the value of time. The scatter plot of transformed value of time (VOT) vs. median age (AGE) in Figure 5 shows a positive relationship. That is, median age increase affects the increase in transformed value of time. The slope is 0.0872, meaning that if median age increases by 1 year, the actual increase in the transformed value of time will be $0.0872/hr. Moreover, p-value of this individual regression is 0.0054, which also indicated high significance of this relationship (Table 7).

The scatter plot of transformed value of time (VOT) vs. AADT in Figure 5 shows a positive relationship. That is, AADT increase affects the increase in transformed value of time. The slope is 0.003, meaning that if AADT increases by 1 (×1000) vehicles per day, the actual increase in the transformed value of time will be $0.003/hr. The p-value of this individual regression is 0.2012, which also indicated low significance of this relationship (Table 7).

Table 7: Scatter plots: Critical parameters

Scatter Plots for Trans (VOT) vs Independent Variable			
Independent Variable	Slope	R-Square	P-value
AGE	0.0872	0.357	0.0054
AADT	0.003	0.089	0.2012
EHI	0.089	0.627	0.0001
SIZE	0.0003	0.006	0.7489

The scatter plot of transformed value of time (VOT) vs. effective hourly income (EHI) in Figure 5 shows a positive relationship. That is, median age increase affects the increase in transformed value of time. The slope is 0.089, meaning that if effective hourly income increases by $1/hr, the actual increase in the transformed value of time will be $0.089/hr. Moreover, p-value of this individual regression is 0.0001, which also indicated high significance of this relationship (Table 7).

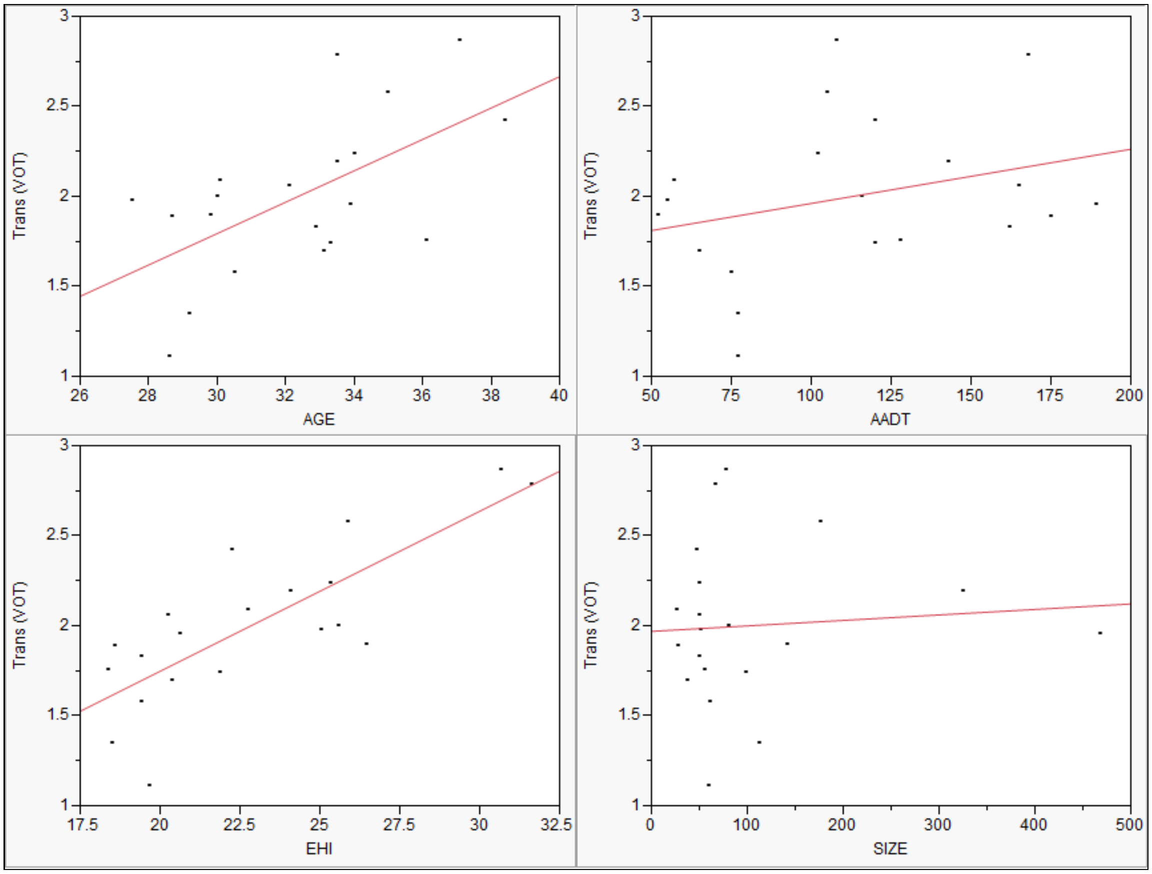


Figure 5: Scatter plot between transformed value of time and independent variables

The scatter plot of transformed value of time (VOT) vs. size of city (SIZE) in Figure 5 shows a positive relationship. That is, size of city increase affects the increase in transformed value of time. The slope is 0.0003, meaning that if size of city increases by 1 sq. miles, the actual increase in the transformed value of time will be $0.0003/hr. The p-value of this individual regression is 0.7489, which indicated low significance of this relationship (Table 7).

5.3 Multiple Regression Analysis

Multiple regression analysis was performed with the identified variables. The method of "backward elimination" was used in this study. In this method, multiple regression analysis is performed and an insignificant variable (based on p-value) is eliminated in the first step. The regression analysis is performed again with remaining variables to eliminate another insignificant variable. This process is repeated until all the variables left the regression analysis are significant.

Now that independent variables have been identified, multiple regression analysis was performed with four identified variables. Table 8 shows the parameter estimates of step 1 of regression analysis. It was observed that p-value for size of city (SIZE) is 0.3722. Therefore, the variable size of city was eliminated from the analysis.

Table 8: Regression analysis using backward elimination (Step 1)

Parameter Estimates				
	Estimate	Std Error	t-ratio	p-value
Constant	-1.742	0.4975	-3.50	0.0032
AGE	0.0503	0.0163	3.09	0.0075
AADT	0.0025	0.0012	2.22	0.0423
EHI	0.0815	0.0117	6.95	0.0001
SIZE	-0.0004	0.0004	-0.92	0.3722

Table 9 shows the results of step 2 of regression analysis. It was observed that the p-values for variables median age (AGE) and effective hourly income (EHI) were less than 0.05. On the other hand, the p-value for AADT was 0.0581. However, since this p-value was very close to 0.05, the variable AADT was not eliminated from the regression analysis. Hence, the three variables median age (AGE), AADT, and effective hourly income (EHI) were found to be significant in the regression model.

Table 9: Regression analysis using backward elimination (Step 2)

Parameter Estimates				
	Estimate	Std Error	t-ratio	p-value
Constant	-1.7164	0.4944	-3.47	0.0031
AGE	0.0499	0.0162	3.08	0.0072
AADT	0.0022	0.0011	2.04	0.0581
EHI	0.0810	0.0117	6.94	0.0001

Table 10: R-square and adjusted R-square values for regression model

Total df	R-square	Adjusted R-square	F statistic	p-value	SSE
19	0.8418	0.8122	28.3830	0.0001	0.577

Table 10 presents some important statistics obtained from ANOVA analysis to test significance of the model. It was observed that p-value for ANOVA was 0.0001, which proved that the significance of model. The adjusted R-square value for regression model was 0.8122, which meant that almost 81.22% of the variability in the transformed VOT was explained by the three parameters: median age (AGE), AADT, and effective hourly income (EHI). The remaining 18.78% may be due to unknown factors.

Based on the regression analysis, Equation 1 was established as a basic equation to predict value of time with identified factors. According to Table 9, the p-value for constant term was 0.0031, meaning that the equation will have a constant term. Equation 2 was obtained by rearranging Equation 1, to predict value of time in terms of dollars-per-hour.

$$\mathrm{Log_e(VOT - 7) = 0.0499 * AGE + 0.0022 * AADT + 0.0810 * EHI - 1.7164} \quad \text{(Equation 1)}$$

$$\mathrm{VOT = 7 + e^{0.0499*AGE+0.0022*AADT+0.0810*EHI-1.7164}} \quad \text{(Equation 2)}$$

Following meanings of coefficients can be derived from the model:

1. β_1 is 0.0499 meaning that if the median age (AGE) increases by one year, value of time (VOT) will increase as much as $0.0499/hour as a transformed value
2. β_2 is 0.0022 meaning that if the annual average daily traffic (AADT) increases by one thousand vehicles per day, value of time (VOT) will increase as much as $0.0022/hour as a transformed value
3. β_3 is 0.0810 meaning that if the effective income (EHI) increases by one dollar-per-hour, value of time (VOT) will increase as much as $0.0810/hour as a transformed value.

5.4 Adjusted Model for Inflation

When calculating value of time, time variability may become an important issue because value of time is likely to be affected by inflation or deflation over time. The issue of time variability was addressed by introducing inflation factor ΔT (Son et al. 2011). Equation 3 shows the adjusted model that reflects time adjustment factor.

Inflation factor = $\Delta T = (1 + i)^{n}$

Where, i = California inflation rate for the fiscal year

n = (projected year – current year)

$$VOT = (7 + e^{0.0499*AGE+0.0022*AADT+0.0810*EHI-1.7164}) * \Delta T \qquad \text{(Equation 3)}$$

6 REGRESSION MODEL VALIDATION

This research effort implemented multiple linear regression analysis to examine relationship between value of time and some of the identified factors. The adjusted R-square value was found out to be 0.8122, which suggested that the 81.22% variability of the model was explained by median age, annual average daily traffic, and effective hourly income. This suggested that the reliability of prediction model.

The PRESS statistic is one of statistical parameters which tests regression model's validity. For a sample of *y*-values and a proposed regression model relating *y* to a set of *x*'s, the first observation is removed and the model is fitted using the remaining *n-1* observations. Based on the fitted equation, the first observation (denoted by y_1*) and the residual y_1 - y_1*. This process is repeated *n-1* times, successively removing the second, third,…..,*n*th observation, each time computing the residual for the removed observation (Ott and Longnecker 2010). The PRESS statistic is defined as:

$$PRESS = \sum_{i=1}^{n} (y1 - y1*)^2$$

The PRESS statistic cannot be less than the value of SSE (Sum of Squares Error), but if the value of the PRESS statistic is close to the value of SSE, it proves that the proposed model can predict new data with high feasibility. Moreover, PRESS statistic should not be too large as compared to SSE. For this study, PRESS statistic was calculated using JMP10.

Table 11: Test for validity using PRESS statistic

Regression Model		
PRESS statistic	SSE	PRESS/SSE ratio
0.737	0.577	1.27

The PRESS to SSE ratio was 1.27 which meant that PRESS statistic value was close to SSE, therefore the model effectively predicted value of time (Table 11).

7 CONCLUSIONS

The primary objective of this research was to investigate the influence of socio-demographic and traffic factors on the value of time. Multiple linear regression technique was used to develop a predictive model to determine value of time heterogeneously. The results of the regression analysis proved the significance of median age, annual average daily traffic, and effective hourly income, in calculating value of time. The ANOVA analysis proved that the model is significant. Moreover, validity of the model was tested using PRESS statistic. The regression analysis indicated that effective hourly income was the most significant of three factors to influence value of time. Median age was found to be the second most significant factor followed by annual average daily traffic. This model will be particularly useful for Caltrans. However, methods used to develop the model can be helpful to other STAs to develop their models for respective states. The findings and ideas of this research effort can assist STAs in developing value of time strategies by understanding factors such as median age, annual average daily traffic, and effective hourly income.

7.1 Interpretation of Results

The statistical analysis used transformation technique to convert data into normal distribution. The p-value for regression model was 0.0001, which suggested that the model is significant.

The significance of each variable was tested using regression model. Backward elimination method was performed to eliminate insignificant variables. In the process, the variable size of city (SIZE) variables was rejected. The final regression analysis revealed significance of three factors namely, median age, annual average daily traffic, and effective hourly income. The meaning of suggested prediction model can be explained in this way:

Prediction Model:

$$\mathrm{VOT} = (7 + \mathrm{e}^{0.0499*\mathrm{AGE}+0.0022*\mathrm{AADT}+0.0810*\mathrm{EHI}-1.7164}) * \Delta\mathrm{T}$$

1. The median age (AGE) variable has a positive relationship with value of time (VOT), meaning that if median age increases, VOT would also increase. In many studies, age has been found to be a critical factor influencing value of time (Brownstone et al. 2003; Kato et al. 2011; Small et al. 2005).
2. The annual average daily traffic (AADT) variable has a positive relationship with value of time, meaning that if annual average daily traffic increases, value of time also increases.
3. The effective hourly income (EHI) variable also has a positive relationship with value of time (VOT), meaning that if effective hourly income increases, value of time also increases. This is the first study which identifies 'effective hourly income' as a factor. However, many studies have found positive relationship

between value of time and hourly income (Fosgerau 2006; Santos and Bhakar 2006; Small et al. 2005).

4. Since, effective hourly income (EHI) is expressed in terms of median hourly household income and cost-of-living index, it can be concluded that:
    - If cost-of-living index (COLI) increases, with median hourly household income (MHHI) as constant, effective hourly income would decrease, meaning that value of time (VOT) would decrease
    - If median hourly household income (MHHI) increases, with cost-of-living index (COLI) as constant, effective hourly income would increase, meaning that value of time (VOT) would increase

7.2 Future Research

This research effort was the first of its kind to develop a model with all the identified factors, especially cost-of-living index and annual average daily traffic. The adjusted R-square value of the proposed model was high. However, 18.78% variability of the model was explained by unknown factors such as vehicle occupancy, educational qualifications, frequency of travel, etc. which was out of scope of this research. Future research should focus on developing a more comprehensive model by accounting all other factors. Moreover, this research was limited to the state of California. Therefore, similar methodology must be applied to other states for developing VOT models.

Further, a detailed research is required to study the effects of cost-of-living index on value of time.

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APPENDIX

Data: Cost-of-living index (COLI) for California cities

City	Cost of Living Index (COLI)
Los Angeles	1.364
San Diego	1.323
San Jose	1.561
San Francisco	1.64
Fresno	1.173
Sacramento	1.162
Long Beach	1.364
Oakland	1.391
Bakersfield	1.034
Anaheim	1.464
Santa Ana	1.464
Riverside	1.125
Stockton	1.22
Chula Vista	1.293
Fremont	1.607
Irvine	1.464
San Bernardino	1.021
Modesto	1.223
Oxnard	1.324
Moreno Valley	1.134

Data: Effective Hourly Income (2013$/hr) for California cities

City	Effective Hourly Income ($/hr)
Los Angeles	20.63
San Diego	24.10
San Jose	25.88
San Francisco	22.25
Fresno	18.52
Sacramento	21.86
Long Beach	19.42
Oakland	18.39
Bakersfield	26.44
Anaheim	20.27
Santa Ana	18.59
Riverside	25.59
Stockton	19.42
Chula Vista	25.35
Fremont	30.66
Irvine	31.64
San Bernardino	19.68
Modesto	20.39
Oxnard	22.74
Moreno Valley	25.04

Data: Median age and size of city for California cities

City	Median Age (years)	Size of City (Land Area) (Sq miles)
Los Angeles	33.9	468.67
San Diego	33.5	325.19
San Jose	35	176.53
San Francisco	38.4	46.87
Fresno	29.2	111.96
Sacramento	33.3	97.92
Long Beach	32.9	50.29
Oakland	36.1	55.79
Bakersfield	29.8	142.16
Anaheim	32.1	49.84
Santa Ana	28.7	27.27
Riverside	30	81.14
Stockton	30.5	61.67
Chula Vista	34	49.63
Fremont	37.1	77.46
Irvine	33.5	66.11
San Bernardino	28.6	59.2
Modesto	33.1	36.87
Oxnard	30.1	26.89
Moreno Valley	27.5	51.27

Data: Annual Average Daily Traffic (AADT) for California cities

City	AADT (×1000) (vehicles/day)
Los Angeles	189
San Diego	143
San Jose	165
San Francisco	120
Fresno	77
Sacramento	120
Long Beach	162
Oakland	128
Bakersfield	52
Anaheim	165
Santa Ana	175
Riverside	116
Stockton	75
Chula Vista	102
Fremont	108
Irvine	168
San Bernardino	77
Modesto	65
Oxnard	57
Moreno Valley	55