



# Household travel survey method for vehicle kilometers travel estimations: A case study in a developing country

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**KEYWORDS:** Vehicle Kilometers Travelled; Developing Countries; Household Travel Survey; Personal Kilometers Travelled; Transportation Planners.

**ABSTRACT:** Vehicle Kilometers Travelled (VKT) represents number of kilometers travelled by vehicles during a specific period of time in a specific area of concern. Transportation planners, policy makers, urban planners, and estimators of vehicle emission, energy consumption and fuel-price encourage the calculation of VKT for various analytical purposes. However, in most of the developing countries VKT is not estimated due to data challenges. This study aimed at proposing a household travel survey method for estimating VKT in developing countries where timely VKT data are not available. Also, estimating Personal Kilometers Travelled (PKT) seems important in developing countries, since the majority is using public and non-motorized transport modes rather than personal vehicles in those countries. This proposed method allows to collect data that are needed for estimating both VKT and PKT together with socio demographic information. A case study was conducted in three different

regions; Northern, Eastern and Southern areas of Sri Lanka, which is a developing country. Questions were asked regarding to trips in a typical week, trips in holidays, special seasons or vacations, number of passengers travelled, travel modes and, socio demography of the respondent. Pilot surveys were conducted prior to the actual surveys to verify the efficiency of developed questionnaire. Samples were taken satisfying all the selected socio demographic categories within the community. Collected data through surveys were aggregated to annual level and, weighted using relevant census and population data. Weighted VKT and PKT estimates were obtained under each selected socio demographic category. Also, VKT estimates were statistically compared for studying the travel behavior of people across different regions. ANOVA and Post Hoc tests were employed for statistical comparisons. These findings can efficiently be used for transport planning, policy making activities, emission calculations, energy consumption estimations etc. by transport and environmental agencies of the country. The case study revealed the experience of utilizing the household travel survey method in Sri Lanka, making it possible to be replicated in other developing countries as well.

## 1. INTRODUCTION

The sum of distance travelled by all vehicles on a road network is referred to as Vehicle Kilometers Travelled (VKT) or Vehicle Miles Travelled (VMT), depending on the system of units that is being used. VKT is a key metric in transportation planning since it provides a measure of total travel, how travel changes over time and, differences in travel among regions and states (Williams, Chigoy, Borowies, & Glover, 2016). Both personal and commercial travel demand are mainly indicated using VKT, which is highly useful for developing countries. VKT can effectively be used in allocating resources and funds to transport infrastructure development projects. VKT is also a key figure to quantify the use of road infrastructure. Two of the most prominent goals of transportation investments are time savings and, to a lesser extent, improvements in the reliability of travel time (Small, 2012). Most of the developing countries experience heterogeneous traffic conditions and higher levels of congestion on roads, which lead to delays, wasting of fuel, personal or commercial time and, associated costs. VKT is capable of identifying the regions that are travelled more frequently and, makes it possible to allocate resources to these congested regions for maximizing traveller benefits. Another benefit of estimating VKT in developing countries is that, VKT can be utilized in calculating fuel prices/taxes. Also, VKT directly reflects the extent of spatial interaction within society and economy (Bäumer, Hautzinger, Kuhnimhof, & Pfeiffer, 2018).

There is a noticeable trend over the world for encouraging VKT estimations in countries due to arising greenhouse gas emissions, energy consumption and, increasing fuel prices (Cervero & Murakami, 2010). VKT per capita is widely viewed as the strongest single indicator of environmental degradation and resource consumption in the transport sector. Vehicle use intensity, usually expressed in VKT per year is also a crucial factor in estimating vehicular fuel use and emissions (Huo, Zhang, He, Yao, & Wang, 2012). Increased travel/ increased vehicle mileage is responsible for a significant portion for increasing greenhouse gas emissions (Kim, 2015). Therefore, VKT can be identified as one of the key influencing factors for an efficient transportation system of developing countries and, their economies where a rapid growth of population, motorization and urbanization is observed. As VKT is a measure of travel demand, many factors influence the travel demand as well as the VKT. Some of such factors are socio-economic factors, socio-demographic characteristics and growth, changes in the cost of travel, urban sprawl, technological innovation, societal change and, legislative factors. National statistics in the United States of America (USA) show a decreasing trend in VMT per capita in the new millennium. That could be occurred due to demographic and social changes, technological improvements, efforts for compact and, mixed-use developments. (Choi, Gao, & Zhang, 2017). Also, telecommuters replace physical commuting trips by working at home or at locations close to home, however, the total travel impact of telecommuting is uncertain and, the general finding is that the impact is rather small (Hu & He, 2016).

VKT is typically estimated using traffic counts and roadway centreline lengths (Williams et al., 2016). Major roads in many developed countries are now equipped with automated traffic counters, tolling systems and, other technologies that can deliver regular and reliable data on daily traffic flows (Fu, Kelly, & Clinch, 2017). However, this is not the case in all countries. The availability of such data for secondary and tertiary routes is limited in most countries; specially in developing countries. Additional effort is needed to calculate traffic volume of road segments because, Average Daily Traffic (AADT) data are not available in those countries. Even though responsible state agencies are not capable of estimating such data due to many reasons, employing these numerical methods seem impossible in most developing countries. The fuel sale method is another way of calculating VKT. In order to apply this method, the total fuel sale volume of a region and fuel efficiencies of different types of motorized vehicles are required. However, fuel efficiency may differ with different vehicle, road, environmental and, climatic conditions. Therefore, adopting this method will not provide reliable VKT estimates in developing countries. Odometer reading survey method is a successful way of finding VKT during a specific time period. Vehicle users are asked to record daily odometer reading in a travel diary for consecutive number of days and, those can be aggregated to obtain annual VKT later on. Another way of recording odometer reading is, conducting a survey aiming vehicle users. Two odometer readings are required for estimating VKT for a consecutive period of time. Therefore, it can be suggested to obtain odometer reading at the time of emission testing of the vehicle, which is recorded in the vehicle emission test report and, the current odometer reading of the vehicle on the date of survey.

In developing countries, most people do not own personal vehicles and, the main means for mobility are walking, intermediate means of transport and, public transport services (Starkey & Hine, 2014). Therefore, VKT estimates do not reflect the actual travel distance of people in developing countries. This differs from VKT because, the focus of VKT estimates is only for the number of kilometers travelled by motor vehicles, not people. The number of kilometers travelled by each individual as both drivers and passengers, including all motorized and non-motorized transportation modes as bicycles, walking etc. is referred to Personal Kilometers Travelled (PKT). The estimation of PKT is important in identifying travel behaviour and, travel patterns of a community. Also, PKT gives all trip information of an individual in a more detailed manner. Therefore, estimating PKT seems important in developing countries, as well as VKT. Also, PKT is affected by several socio demographic characteristics and, differs from one individual to another individual. Therefore, it is important to analyse such data by considering socio-demographic factors. Estimating VKT using traffic counts and roadway centreline lengths, fuel sale method and, odometer surveys do not provide this information. Therefore, utilizing a method which provides VKT in relation to socio demographic information and, gives information that need to estimate PKT is better and more efficient. Household survey method is more beneficial from this point of view, which provides data to estimate VKT/PKT with socio demographic information of the respondents. In this method, respondents are asked to record their travel information during a considered time period along with their personal information. Questions are raised on trip distances, purpose of trips, number of passengers travelled, mode of travel and, socio demographic information of the respondent such as gender, age, income, residential status etc. These trip distances can be aggregated to annual level, in order to estimate annual VKT and PKT. Compared to other methods, household survey method is preferable to be used in developing countries for estimating VKT and PKT.

The objective of this study was to propose an effective methodology for estimating VKT in developing countries. A questionnaire-based household survey method was proposed and, the method focused not only on VKT and PKT, but also reflected the distribution of VKT and PKT among different socio demographic groups. As described earlier, these detailed VKT/PKT estimations in developing countries are useful to identify mobility patterns and behaviour of local communities. Also, these data can be employed in monitoring and forecasting fuel and energy consumption in transport sector and, emissions. Then, issues within current transport systems can be notified and, future mobility trends, issues and, solutions will able to be predicted. It will have a considerable effect on the economy of a developing country. Accordingly, the study fulfils two research gaps; proposing a method for estimating timely VKT in developing countries with an exemplary case study and, providing an understanding on the changes of VKT with different socio demographic factors. The exemplary case study was conducted in three different areas of Sri Lanka. The purpose of conducting this case study was to demonstrate implementing the proposed methodology and to identify possible challenges in real-world applications.

## 2. LITERATURE REVIEW

### 2.1 Influences on VKT

The VMT growth in the USA has changed due to population growth, increase in total income, demographic changes and, decentralization of metropolitan areas (Noland & Cowart, 2000). VMT is influenced by number of registered personal vehicles, number of licensed drivers, levels of employment, number of households, as well as transportation supply indicators such as number of lane miles, congestion and level of telecommuting, making it necessary for VMT to be presented as a system of multiple structural equations (Choo, Mokhtarian, & Salomon, 2005). Many research studies have been conducted to measure the impacts on VKT due to the modern technology (Yoshimoto & Nemoto, 2005; Jamal, Habib, & Khan, 2017).

An investigation on the determinants of the impact of smartphone use on VKT was conducted in Halifax, Canada under three different scenarios. They were; smart phone usage has reduced VKT, no impact on VKT and, increased VKT (Jamal et al., 2017). A Latent Class Modelling approach has been used in order to examine the changes in VKT due to the usage of smart phones among different socio demographic groups, residential locations and, life styles. The data were obtained from a previously conducted web-based survey. The study focused on the effect of smartphone use on VKT with few factors such as trip maker's characteristics, smart phone usage frequency, neighbourhood and land-use characteristics and, accessibility from major services. The model identified two classes of population, with class one being students and young professionals, whose annual income is less than CAD 15K, and the second, female population with part-time or full-time employment, who are not full-time students. Results revealed that variations existed between class 1 & 2. The determinants that can reduce VKT due to smart phone usage were identified as, online shopping, active transportation as primary mode, home to work/school distance, pro-environment attitude etc. Also, the influence of ride-hailing methods on VKT has been evaluated by some researchers as well (Henao & Marshall, 2019; Tirachini & Gomez-Lobo, 2020).

To estimate VKT in Poland, models were developed using four groups of independent variables (Jamroz & Wachnicka, 2018). Those were socio – economic conditions, land use, transport system and, individual behaviour of population.

Socio – economic conditions include demographics, tradition and culture, economy, industry and its structure, trade, tourism, climate etc. Land use factor refers to density and distribution of population, density and distribution of industry, density and distribution of tourism destinations and, size and distribution of farming lands. Transport system factor denotes available vehicle fleet, transport infrastructure, accessibility of transport and, transport policy. Individual behaviour of population refers to mobility, length of trips, source and destination of trips, preferred means of transport etc. However, experience shows that socio – economic factors are prominent in forecasting VKT. In the study, models were developed considering selected influential factors; demographic and economic measures to represent socio-economic conditions, geographic measures and variables to represent land use and, infrastructure and motorization measures and variables to represent the transport system. A linear model, a log normal model, power model and power-exponential model were developed. The exponential function gave a fair approximation on VKT for years 1960-2012, However, the model was not entirely suitable for long-term forecasts. The study revealed the need of new functions that describe the actual data. It proposed to employ multi-factorial compound models in forecasting long-term VKT.

## 2.2 Travel surveys for estimating VKT

A study was conducted to assess the changes of VKT, after implementing the travel behaviour change program in Melbourne called Travel Smart (Seethaler & Rose, 2009). A before and after travel diary survey and a household-odometer survey were conducted in the study. VKT from week-long odometer readings were aggregated to household level and, average daily household VKT was calculated. It reduced the variability of travel distance recordings among household members and, weekday recordings in travel diaries. The relationship between vehicle fuel economy as a measure of energy efficiency and, VMT as a measure of consumption was examined in Columbia (Munyon, Bowen, & Holcombe, 2018). The VMT data were extracted from the National Household Travel Survey-2009, which was conducted over 13 months in all 50 states and the District of Columbia in the US. It was included several attributes related to households, drivers within the households, vehicles and travel data for each member of the household and, each vehicle. Energy consumption related data such as mileage per gallon per any given vehicle type, gas price data etc. were collected through the Energy Information Administration and Oak Ridge National Labs. Miles driven by each vehicle per annum was estimated based on annualized odometer readings which were recorded using daily trips carried out by each vehicle in the household.

The impacts of housing development designs on VMT were examined in Iskandar, Malaysia (Majid, Nordin, & Medugu, 2014). That was investigated through the data collected by distributing travel diaries and questionnaire forms to households within a sample of housing developments. First, students from selected primary and secondary schools were asked to take travel diaries and questionnaires home and, return the completed documents back in the following week. For additional respondents, travel diaries and questionnaires were distributed to a group of randomly selected households within the sample. Total of 325 forms were collected from households representing 24 housing developments for the study. Another survey was conducted in Beijing, China to assess daily VKT and impact factors, aiming the design of powertrain BEVs and Plug-in Hybrid Electric Vehicles for reducing energy and emissions (Hou, Wang, & Ouyang, 2013). This paper-based survey was conducted to collect VKT data with impact factors such as purpose of travel, travel distance,

transport type respectively for urban and inter-city travels., vehicle characteristics, odometer readings, respondent characteristics etc. Total of 500 questionnaires were distributed among private passenger cars in Beijing. The daily VKT distribution was assessed with the help of software Minitab and, the statistical analysis was conducted using several tests such as Analysis of Variance (ANOVA).

Indian vehicle ownership and travel behaviour was observed by analysing data obtained from a travel survey conducted in Bangalore, Kolkata and, Delhi (Bansal, Kockelman, Schievelbein, & Schauer-West, 2018). Travel survey was conducted using a web-based tool over 1000 respondents during July and August, 2015. The survey asked 77 questions that divided into four categories. Respondents were asked regarding household current vehicle inventory, vehicle usage frequency, VKT by each vehicle, household vehicles sold during past 10 years, future vehicle preferences and, inclination towards electric vehicles. Also, respondents were asked on behavioural changes due to gasoline prices, opinions on helmet laws, importance of vehicle brands, operating costs, travel choices and, demographics. Annual vehicle travel distances were analysed using ordinary least squares linear regression. Multinomial logit and Poisson modelling frameworks were employed in modelling household level vehicle ownership choices. During surveys, respondents who completed the survey less than 13 minutes were assumed to have not read questions thoroughly and, their responses were discarded.

Another study was conducted in Kathmandu Valley, Nepal for estimating road transportation energy demand and, environmental emission (Bajracharaya & Bhattarai, 2016). For modelling transportation energy demand using a long-range energy alternative planning system, four parameters were required. Those were present and future vehicle stock, vehicle use intensity expressed in VKT, vehicle fuel use intensity and, emission factors. Regarding VKT, very few numbers of studies have been done in Nepal. Therefore, authors conducted a vehicle survey in Kathmandu Valley for the year 2013. Based on survey data, average annual VKT for different vehicle types was estimated. As the annual VKT declines with the age of a vehicle, VKT was expressed as a function of vehicle age.

## 2.3 Different methodologies for estimating VKT

VKT and on-road vehicle emissions based on traffic volume and registered vehicles were found in Incheon city, Korea (Jung, Kim, Kim, Hong, & Park, 2017). Applied traffic volumes focused only on arterial roads within the entire road network in the city, creating a difference between VKT based on registered vehicles and traffic volumes. In a study conducted in Houghton Country, Michigan, VKT data were estimated by collecting annual daily traffic counts from 43 traffic survey stations which were located over the study region. Those traffic counts were multiplied with the length of roadway between two survey stations in order to obtain VKT (Chi & Stone, 2005). A zone-level bike ridership model was developed to predict Bike Kilometers Travelled (BKT), in the city of Vancouver, Canada allowing quantification of the impacts of bike network, land use and, road facility variables on BKT (Osama, Sayed, & Bigazzi, 2017). The dependent variable; BKT was calculated using Vancouver Cycling Data Model. It provided bike counts over the city from 2005 to 2011, in order to calculate Annual Average Daily Bike Traffic and, the corresponding bike network link lengths.

The VMT growth of two urbanized areas; Baton Rouge and New Orleans in the US, was estimated in order to introduce a tool for transportation planning and policy making (Renne & Tolford, 2018). Also, the study was aiming at improving the safety measures that could be improved with the VMT



growth. A constrained forecast model was proposed to monitor how VMT impacts on crashes and, to identify possible safety outcomes suitable for travel demand, while forecasting future growth scenarios as well. Further, growth management policy models were developed based on past studies, in order to represent the data. A study was conducted in Beijing, China for collecting necessary data for Battery capacity designs in electric vehicles, considering the diversity of Daily Vehicle Miles Travelled (DVMT) (Li et al., 2016). The collected data were, driving data and charging patterns of drivers including latitude, longitude, velocity, VMT between two consecutive charging etc. Global Positioning System (GPS) equipment were installed in number of Battery Electric Vehicles (BEVs) and Internal Combustion Engine Vehicles. Then the proper capacity of BEVs was analysed in order to satisfy the DVMT. GPS techniques were also used in order to find driving patterns on the distance travelled, when drivers were involved in road accidents in Spain (Ayuso, Guillen, & Marin, 2016).

It can be found that a few limitations exist in implementing VKT estimation methods in developing countries. The methods proposed under homogeneous traffic conditions in developed countries cannot be replicated in developing countries, due to the heterogeneity of traffic conditions. Inadequacy of data such as traffic volume data and geometric data weaken VKT estimations, which utilize advanced numerical methods. Also, most probably in transport infrastructure development, only economic viability of projects is assessed neglecting current trends and, future growth scenarios. Therefore, the involvement of responsible agencies for estimating VKT is comparatively less in developing countries. Perhaps, this situation is caused due to lack of funding allocations for implementing those techniques and, the lack of awareness or knowledge among the transportation communities. Travel diary surveys, odometer surveys and, questionnaire surveys seem feasible in developing countries. However, very few numbers of studies have been attempted. As examples, household surveys have been conducted in Southern and Northern provinces of Sri Lanka, in order to collect VKT and PKT for years 2016 and 2017 respectively (Weerasekera & Amarasingha, 2017; Amarasingha & Balasayanthan, 2018). The respondents participated in the surveys were asked to recall the recent commuter trips and, VKT and PKT were estimated for the year.

### 3. METHODOLOGY

#### 3.1 Household travel survey method for estimating VKT in developing countries

Questionnaire based household travel survey method was conducted aiming at collecting trip information together with socio demographic information of respondents. Table 1 shows the selected socio demographic factors for the survey. Sufficient samples of respondents were drawn representing different socio demographic categories in communities over selected areas. For this purpose, population and census data were used. Pilot surveys were conducted in all three areas prior conducting actual surveys. That was useful to verify the efficiency of developed questionnaires and, to identify required sample sizes for actual surveys. Interviews were more efficient in obtaining travel information of respondents, rather distributing and collecting questionnaires back. VKT of respondents was calculated from travel data obtained from surveys and, aggregated to annual level. Then, according to selected socio demographic factors, VKT was weighted and normalized to obtain VKT per person per year. For further evaluations and demonstrations of VKT in different regions/states, statistical analysis methods were performed on VKT estimates.

Category	Sub-Category
Gender	Male / Female
Age (in years)	15-24
	25-34
	35-44
	45-54
	55-69
Employment Status	Employed / Unemployed
Residential Area	Urban / Rural
Income (In thousands LKR per month)	<25
	25-50
	50-75
	75-100
	100-125
	>125

Table 1. Socio demographic parameters taken into consideration.

#### 3.2 Analytical components

Data collected and weighted through household surveys can be analysed using several statistical tools. ANOVA is one of statistical hypothesis testing methods, which is widely used to analyse and check the existence of statistically significant differences among two or more independent groups (Sullivan, 2019). When the assumption of Classical ANOVA; homogeneity of variance among groups is violated, it is recommended to use Welch's ANOVA test, which is an extension to the Classical ANOVA. Since the assumption of homogeneity of variance was violated by the acquired data set, Welch's ANOVA test was employed in this study. The test statistic for Welch's test can be expressed as below (Mendes & Akkartal, 2010).

$$(1) F_{welch} = \frac{\sum_{i=1}^k W_i (\bar{X}_i - X'_{..}) / (k-1)}{[1 + \frac{2}{3}(k-2)\Delta]}$$

Where, weight  $W_i$  to reduce the effect of heterogeneity of variance can be denoted as,

$$(2) W_i = \frac{n_i}{S_i^2}$$

$$(3) X'_{..} = \frac{\sum_{i=1}^k W_i \bar{X}_i}{\sum_{i=1}^k W_i}$$

Lambda, which is based on weights can be expressed as,

$$(4) \Delta = \frac{3 \sum (1 - W_i / \sum_{i=1}^k W_i)^2 / (n_i - 1)}{(i^2 - 1)}$$

Where,

$n_i$  = Sample size in the  $i^{\text{th}}$  group,  $S_i$  = Observed Sample variance for the  $i^{\text{th}}$  group,  $\bar{X}_i$  = Sample mean for the  $i^{\text{th}}$  group.

Once significant differences are identified using ANOVA tests, Tukey's Honestly Significant Difference (HSD) test can be applied to detect the sample that deviated creating the significant difference (Rafter, Abell, & Braselton, 2002; Abdi & Williams, 2010). Also, Eta-Squared estimates can be obtained to express the effect size of identified significant differences as large effect, medium or as small. Allowing unequal sample sizes between two treatments, Tukey-Kramer formula; a modified version of Tukey's HSD test was used in order to compute the critical differences of sample means. Games-Howell method can be used when unequal variance among treatments and, unequal sample size is detected. Games-Howell method gives the best performance for pairwise comparisons. This method uses the formula for Welch's approximate degree of freedom, to obtain approximate con-

fidence interval for the difference between two means based on student's t test. In this study, Classical ANOVA, Welch's ANOVA, Tukey-Kramer and, Games-Howell methods were used for the statistical analysis based on the test assumptions, homogeneity of variances among groups. The Tukey-Kramer formula can be given as follows (Black, 2009).

$$(5) \quad q_{\alpha, k, N-K} \sqrt{\frac{MSE}{2} \times \left( \frac{1}{n_r} + \frac{1}{n_s} \right)}$$

where,

$n_r$  = Sample size for  $r^{\text{th}}$  sample,  $n_s$  = Sample size for  $s^{\text{th}}$  sample, MSE = Mean Squares Error.

The  $q$  statistic in Tukey's test is essentially a modified  $t$ -statistic that corrects for multiple comparisons which can be denoted as,  $q_{\alpha, k, N-K}$  where the studentized range distribution of  $q$  can be defined as,

$$(6) \quad q = \frac{Y_{\max} - Y_{\min}}{SE}$$

where,

$Y_{\max}$  or  $Y_{\min}$  = Larger and Smaller means of two groups being compared, SE = Standard Error for the entire design.

#### 4. CASE STUDY

The household questionnaire survey was conducted in Southern, Northern and, Eastern areas of Sri Lanka. Sri Lanka is an island located in the Indian Ocean, a South-Asian country, with a 65,610 km<sup>2</sup> land area. Southern, Northern and Eastern areas of Sri Lanka occupy 5,544 km<sup>2</sup>, 8,884 km<sup>2</sup> and 9,996 km<sup>2</sup> respectively, covering 37.2% land area from the total land area of the country. Southern area consists of both coastal and inland environment including Galle, Matara and, Hambantota areas. Subsistence farming and fishing is the main source of income of the people in this geographic region. The area gives the shelter for national and international ports, harbours and airports, contributing to the national economy in considerable amounts. Jaffna is the capital city in Northern area of the country and, this area was exposed to the civil war in Sri Lanka over 30 years, up to the year 2009. During this eleven year of period from 2009 to 2020, people have been re-settled in the area and, the infrastructure development is being undertaken by both state and private sectors. This area is directly connected to the transportation network of the country by roadways and, railways. The Jaffna International Airport is one of the most predominant airports in Sri Lanka. Eastern area has a primary, agriculture-based economy which is supported by paddy, milk and fish production. Few export processing zones and other industries are under operation, aiming the international trade through the Trincomalee harbour. Also, the tourism industry is one of the main ways of income for the people in this area. This area is also healing from the civil war occupied over three decades. The selected three areas represent the travel behaviour of the local community, that consisted of different ethnic groups, religions such as Buddhism, Hinduism, Roman Catholic, Islamic etc., native languages such as Sinhalese, Tamil etc. and, cultures. Since the selected areas show a blend of a local community, it would be a good representative sample which indicates the entire community of Sri Lanka. Figure 1 shows the geography of Sri Lanka and, the shaded portion shows the selected three areas for the study.

Prior to the main surveys, three pilot surveys in each area were conducted to assess the efficiency of the developed questionnaire and to identify sufficient samples for the main surveys. Using the experience and data obtained from the pilot surveys, the main questionnaire form was updated. Then,

sufficient sample sizes were derived for actual surveys that required to satisfy different socio demographic categories in communities. Pilot surveys were aimed at obtaining samples not less than 32 from each area. To achieve that, 120 samples were distributed in each area. It resulted 35 completed questionnaires from Southern area, 60 from Northern area and, 100 from Eastern area. Questions related to trip distances, travel modes, number of passengers, purpose of travelling and, socio demographic factors of the respondent were included in the questionnaire form. During pilot surveys, it was identified that some respondents refused to answer for some specific questions. As an example, few respondents were not comfortable of saying their average monthly income, home address, age etc. Such defectives were mostly found in Southern area resulting an effective sample size of 35 and, the least number of defectives were found in Eastern area with 100 effective samples. Therefore, the questionnaire was updated by introducing ranges for socio demographic categories, as they can select the corresponding range of income, age etc. Also, it was identified that the initial questionnaire was time consuming and, some respondents were not interested in spending their time in answering all the questions. This was also considered during the actual survey design. Table 2 shows a summary of the finalized questions raised at main surveys.

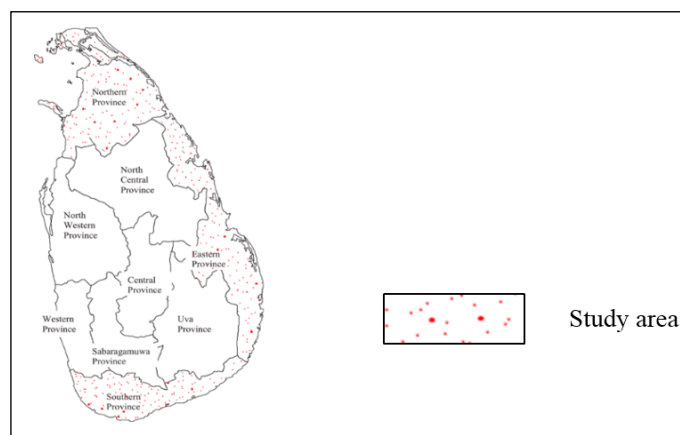


Figure 1. Shaded study area in the map of Sri Lanka.

Question raised	Description
Socio demographic information	Gender, age, employment status, residential area and average monthly income of the respondent
Trip information for a general week from Monday to Sunday	Number of kilometers travelled, vehicle mode and number of passengers participated in each day
Trip information for special holidays/seasons such as special monthly holidays, school vacations, New year season and other annual trips/tours	Number of kilometers travelled, vehicle mode and number of passengers participated

Table 2. Summary of the questions raised in the main questionnaire survey

Northern, Southern and Eastern areas were visited for both pilot and actual surveys. Questionnaires were distributed randomly among the residents in those areas. As an example, the researchers visited both urban and rural areas and, interviewed people who met randomly at houses, bus stops, shops, supermarkets etc. Therefore, the survey was completed by the interviewer at the first call. According to

the selected socio demographic factors, possible population categories within the community were obtained using census data of the country. The minimum number of samples that represented each socio demographic category within the community was satisfied during surveys. For calculating actual sample sizes, Equation 7 & 8 with a 90% level of accuracy were used (Krebs, 2013).

$$(7) \text{ Sample size} = \frac{(\text{coefficient of variation})^2 * (\text{standard normal variant})^2}{(\text{level of accuracy})^2}$$

Standard Normal Variant is for the probability of a type II error, where,

$$(8) \text{ Coefficient of variation} = \frac{\text{observed standard deviation}}{\text{observed mean}}$$

Accordingly, the estimated sample sizes were 410 from Southern area, 224 from Northern area and, 330 from Eastern area. For achieving required sample sizes, 482 questionnaires in Southern area, 300 questionnaires in Northern area and, 412 questionnaires in Eastern area had to be distributed. Excluding incompletely returned questionnaires, actual sample sizes were achieved in each area. The response rates for Southern, Northern and Eastern areas were 85%, 75% and, 80% respectively. Table 3 shows the required number of samples from each socio demographic category in each area. All sample distribution requirements were satisfied during surveys. However, census data were not available in Sri Lanka under different income categories. Therefore, representing number of samples could not be defined for income categories. The data were collected considering one year of time period, from July 2016 to June 2017.

For the easiness of recalling trip information during the year, trips in a typical week and trips in special holidays and seasons were asked separately. Asking to recall trips for few days may increase the validity of information, however, it would not represent the total number of kilometers travelled by a person when annual trips/tours, seasonal trips/tours etc. are omitted from the estimation. It will lead to biased VKT/PKT estimates, when total kilometers for few days are aggregated to the annual level. In this study, trip information for a typical week and trip information in special vacations/holidays/seasons were aggregated to annual level in order to get a more accurate VKT/PKT per person per year. In order to obtain VKT/PKT per person per year in a specific area, VKT/PKT values estimated for each individual in the sample were weighted. The weightages were estimated considering population and census data of specific areas related to select-

ed socio demographic information; age, gender, employment status and, residential area. Weighted VKT/PKT per person per census was estimated using the weightings of all socio demographic groups.

#### 4.1 VKT and PKT estimates

Weighted VKT and PKT were analysed using ANOVA and Post-Hoc tests, in order to compare the results statistically in selected three areas. Following results and comparisons were made utilizing those statistical evaluation methods. Table 4 presents a summary of VKT and PKT with respect to the selected socio demographic features in three study areas.

In Southern area, males and females have travelled more similarly. As shown in Table 4, VKT per a female was 7,004 km/year in Southern area and, it was 7,015 km/year for a male. PKT was recorded as 32,802 km/year and 28,611 km/year, for a female and a male respectively. VKT per an employed person was 10,424 km/year and, for an unemployed person it was 3,595 km/year. PKT per an employed person was 49,809 km/year and, for an unemployed person it was 11,604 km/year. An urban residential person travelled 6,574 km/year and, a rural residential person travelled 7,445 km/year during 2017. In Southern area, rural people travelled more as both drivers and passengers. People in age between 25-34 years travelled more compared to the people in other age categories. Also, the people whose income between 75,000 and 100,000 LKR had the highest VKT and, a person with a 50,000-75,000 LKR monthly income had the highest PKT, compared to the other categories of income.

Northern area of Sri Lanka shows variations in VKT and PKT, as VKT per a male and a female were 7,413 km/year and, 7,401 km/year respectively in the year 2017. In addition to that, PKT per a male was 19,092 km/year and, for a female, it was 10,814 km/year. The VKT value of rural residences was 7,867 km/year and, for urban residences that was 6,947 km/year. Also, a rural passenger travelled 15,334 km/year and, an urban passenger travelled 14,571 km/year. A person in the age between 25 and 34 years travelled more compared to a person in other categories and, also, a person within the age group of 15-24 travelled less compared to others. Employed people in Northern area travelled more compared to unemployed people during the year 2017. A person with a household income between 100,000 and 125,000 LKR had the highest VKT of 9,453 km/year compared to other income categories. The highest PKT of 23,288 km/year, was reported for a person who had a monthly income of 50,000-75,000 LKR. A person with a household income below 25,000 LKR travelled less compared to other categories.

Socio demographic category	Sub category	Population percentage in Southern area	Sample distribution in Southern area	Population percentage in Northern area	Sample distribution in Northern area	Population percentage in Eastern area	Sample distribution in Eastern area
Gender	Male	47.95%	197	46.96%	105	47.60%	157
	Female	52.05%	213	53.04%	119	52.39%	173
Age in years	15-24	15.4%	90	18.2%	58	18.2%	90
	25-34	14.5%	86	14.9%	48	16.2%	80
	35-44	13.5%	80	11.6%	37	12.3%	61
	45-54	12.2%	72	11.0%	35	10.5%	52
	55-69	13.8%	82	14.2%	46	9.4%	47
Employment status	Employed	47%	193	45.89%	103	46.37%	153
	Unemployed	53%	217	54.11%	121	53.63%	177
Residential area	Urban	10.6%	44	16.7%	37	25.1%	83
	Rural	87.7%	366	83.3%	187	74.9%	247

Table 3. Samples required for satisfying each socio demographic category in each area

In Eastern area of the country, VKT per a female was 12,092 km/year and, for a male it was 7,704 km/year showing that females travelled more compared to males. PKT for a female was 24,878 km/year and, for a male, PKT was 20,231 km/year. People within 55-69 years age group in Eastern area travelled more compared to other ages and, the age group of 45-54 years travelled less compared to others. VKT per an employed person was 15,618 km/year and, for an unemployed person, it was 4,178 km/year. PKT of an employed person was 32,435 km/year and, for an unemployed person, PKT was 12,674 km/year. A rural residential person travelled 18,211 km/year and, an urban residential person travelled 1,585 km/year during the year. Also, rural passengers travelled more compared to urban passengers. People whose income was in between 25,000-50,000 LKR drove more compared to the other categories and, the corresponding VKT and PKT were 13,613 km/year and 41,813 km/year respectively.

In Southern and Northern areas, VKT of males and females do not show any noticeable difference. PKT was higher for males in Northern area, while other areas showed a higher PKT for females. In almost all the cases PKT was higher than VKT, this may be because people travelled more as passengers when compared to drivers. In all areas, VKT and PKT were higher for employed people rather unemployed people and, rural passengers have travelled more with respect to urban passengers as well. This finding can be caused due to many reasons, especially trip distances are located closely together, resulting shorter trips of urban people. In Southern and Northern areas, VKT and PKT of people within age 25-34 years were higher. This may be happened because, people within this age range are effectively involved for the work force of the country creating higher number of daily trips for their employments. However, in Eastern area, a person within the 55-69 age range reported the highest VKT and PKT among five age groups. According to the income categories, the highest VKT was reported in Eastern area for the income range 25,000 - 50,000 LKR and, the highest PKT was reported in Southern area for the income range 50,000-75,000 LKR.

#### 4.2 Mode of travel

Figure 2 presents PKT of Southern area of Sri Lanka, based on travel modes; car, van, jeep, motor bicycles, foot bicycles and, three wheelers. Figure 3 presents vehicle modes and PKT in Northern area and, the corresponding data in Eastern area are presented in Figure 4. According to the obtained data of travel modes, a male passenger has mostly travelled in vans in Southern area, motor bicycles in Northern and, cars in Eastern area. For female passengers, most of them have selected their major travelling mode as vans in Southern area, motor bicycles in both Northern and Eastern areas. The frequently used travel mode of employed people in Southern area was van, in Northern area it was motor bicycles and, Eastern area, cars. The people of age categories 15-24, 25-34, 35-44 and 55-69 in Southern area, selected vans as their most convenient travel mode, while a passenger in 45-54 age category mostly travelled in three wheelers. In Northern area, 15-44 and 55-69 age passengers travelled more in motor bicycles and, passengers within the age range 45-54 used jeeps more for their travelling. In Eastern area, 15-34 age passengers used motor bicycles as their predominant travel mode, however, for people within 35-54 age, it was cars. For urban passengers, predominant travel modes were, vans in Southern area, jeeps in Northern area and, motor bicycles in Eastern area. For rural passengers the most frequently used travel modes were, vans in Southern, motor bicycles in Northern and Eastern areas.

#### 4.3 Comparison of VKT data

Results from Classical ANOVA, Welch's ANOVA and Post Hoc tests; Tukey-Kramer and Games-Howell, are presented in Table 5 and Table 6 respectively. When group variances were not equal, Welch's ANOVA and Games-Howell methods were used on behalf of Classical ANOVA and, Tukey-Kramer Post hoc tests. In order to fulfil the normality assumption in ANOVA, log transformation of data was obtained. There were few cases that the null hypothesis was rejected, where null hypothesis was,  $H_0 = \mu_1 = \mu_2 = \dots = \mu_k$ . That means, at least one mean under the relevant category differed among three means from three different study areas. For Welch's ANOVA and Post Hoc tests,

Factor	Sub-Factor	Weighted VKT (in kilometers/year/vehicle)			Weighted PKT (in kilometers/year/person)		
		Southern	Northern	Eastern	Southern	Northern	Eastern
Gender	Male	7015	7413	7704	28611	19092	20231
	Female	7004	7401	12092	32802	10814	24878
Age (in years)	15-24	4280	4523	7961	17306	18705	14716
	25-34	8564	9050	8202	30847	12933	20031
	35-44	8294	8764	11479	34491	16697	30383
	45-54	6339	6699	6605	20120	15833	15180
	55-69	7570	7999	15241	50767	10596	32463
Employment Status	Employed	10424	11015	15618	49809	21270	32435
	Unemployed	3595	3799	4178	11604	8635	12674
Residential Area	Urban	6574	6947	1585	22437	14571	3736
	Rural	7445	7867	18211	38976	15334	41373
Factor	Sub Factor	Unweighted VKT (in kilometers/year)			Unweighted PKT (in kilometers/year)		
		Southern	Northern	Eastern	Southern	Northern	Eastern
Income (in thousands LKR per month)	<25	3744	5340	7601	13209	9333	26298
	25-50	7736	7504	13613	35224	14463	41813
	50-75	10813	8061	9822	55870	23288	24347
	75-100	11533	8869	8877	46408	19071	20853
	100-125	4123	9453	7844	15236	21371	18772
	>125	1100	7648	9315	2200	12229	25218

Table 4. Summary of estimated VKT and PKT in Southern, Northern, and Eastern areas.



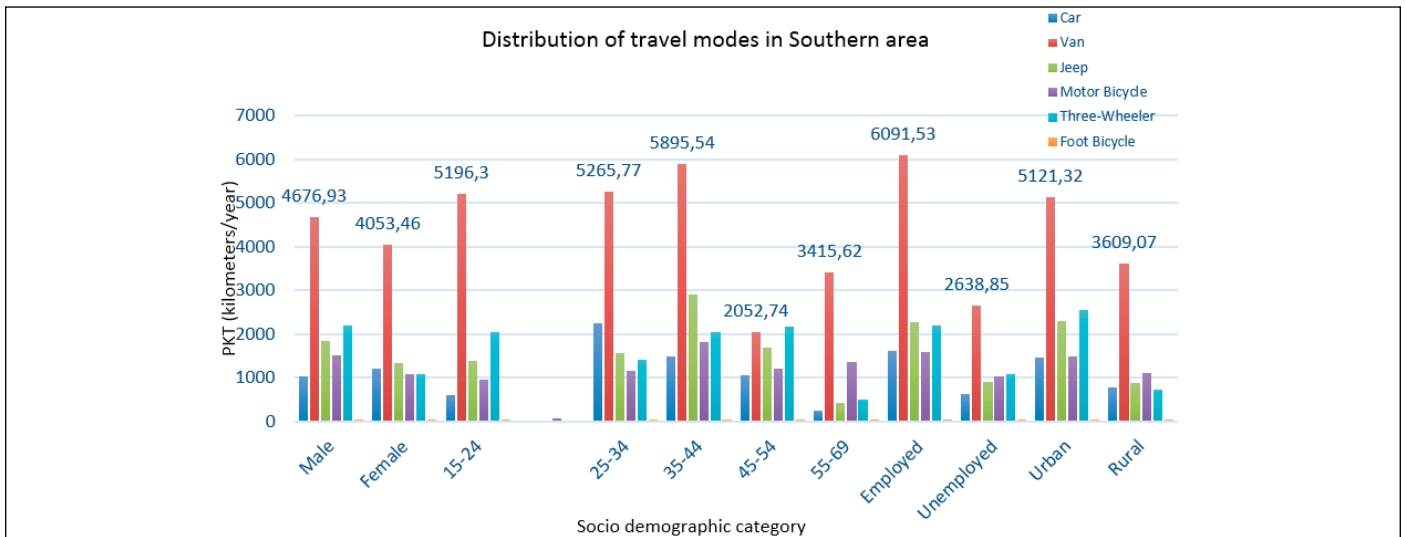


Figure 2. PKT (in kilometers/year) of Southern area based on travel modes.

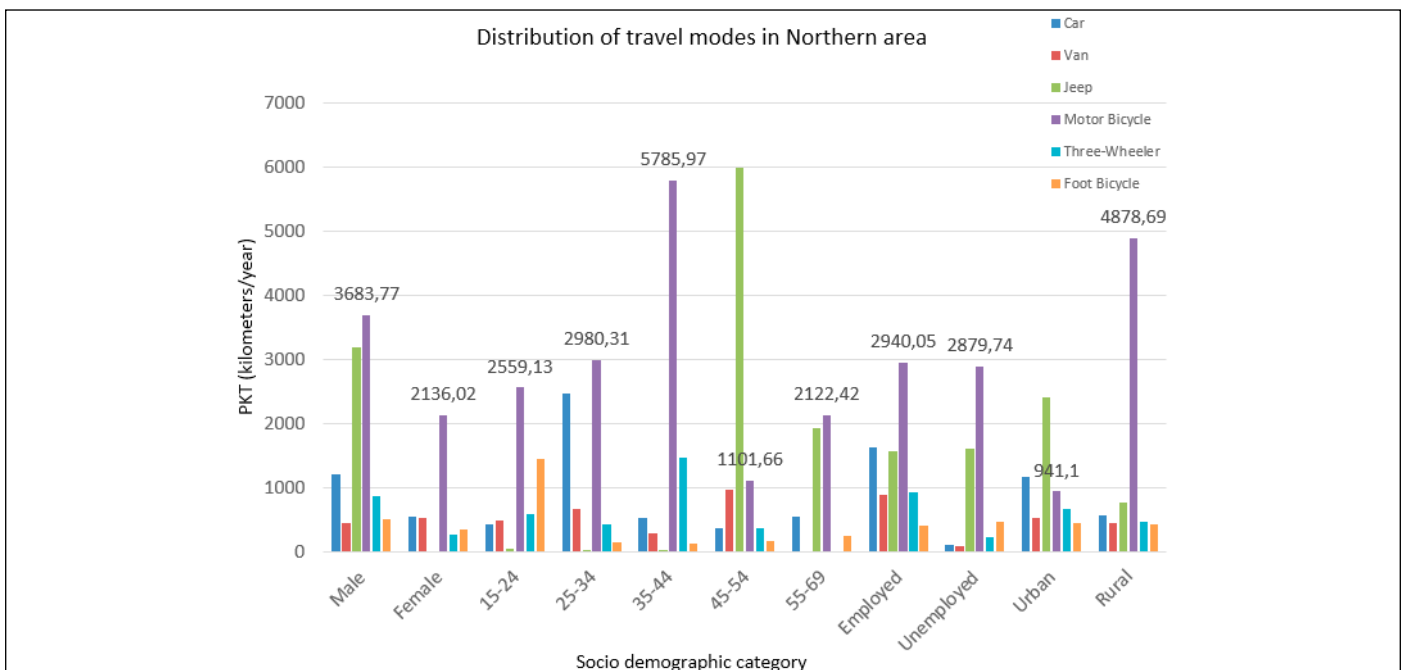


Figure 3. PKT (in kilometers/year) of Northern area based on travel modes.

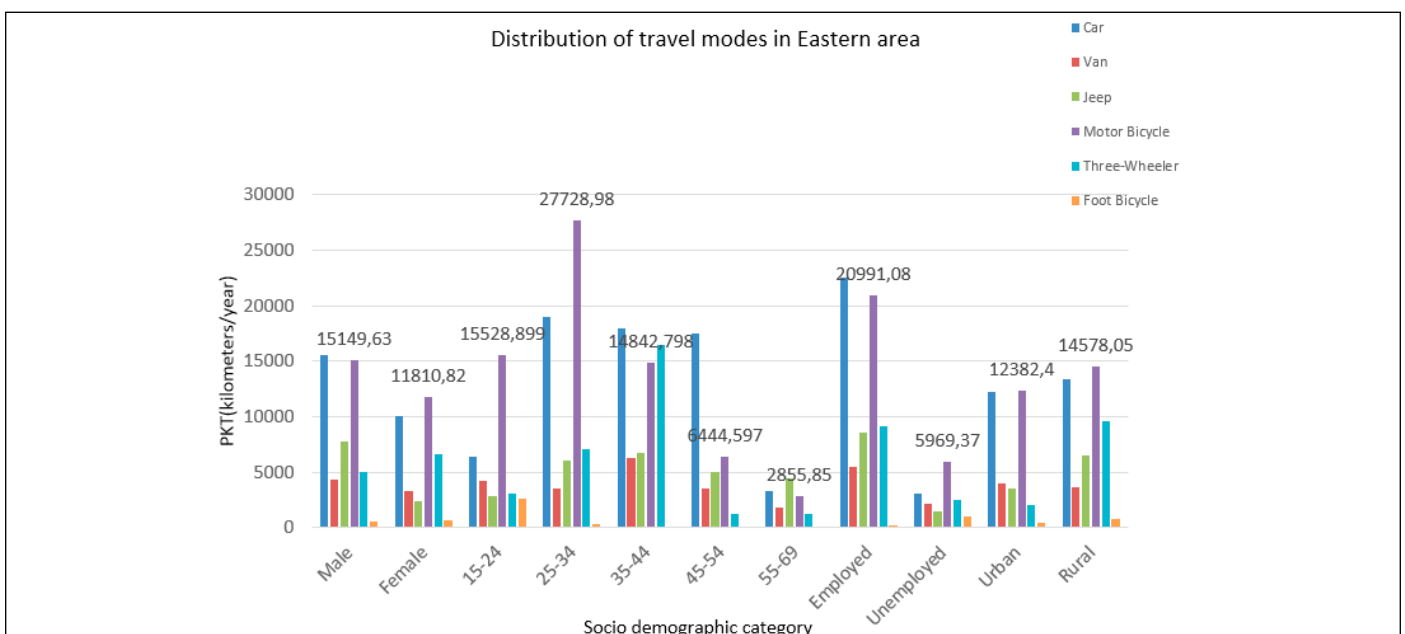


Figure 4. PKT (in kilometers/year) of Eastern area based on travel modes.



p value was compared with the level of significance ( $\alpha = 0.05$ ). If  $p$  value  $< \alpha$  level,  $H_0$  was rejected. As shown in Table 4 and 5, important findings were generated from ANOVA and Post Hoc tests regarding VKT in different areas. The effect size of statistically significant differences between areas were presented using Eta-Squared estimates. Statistical analyses were conducted using SPSS software.

These similarities and differences among areas could be used for developing transport policies, improving the mobility of these areas and the entire country. As VKT always represents a vehicle, annual VKT estimates can be used in transport planning purposes such as estimating vehicle emissions, calculating energy consumption, analysing crashes, estimating crash rates per VKT, assessing traffic impacts and, thereby making road safety policies and allocating resources. One of emerging benefits of estimating VKT is, giving solutions for congestions on roads in developing countries. To avoid the congestion, remedial actions can be implemented in order to reduce VKT in those congested areas. VKT reduction gives many advantages such as lower accident rates,

improved air quality, promoting non-motorized transport modes and, thereby, increase of physical activities, promoting public transport services and, many other business benefits as well (Boarnet, Burinskiy, Deadrick, Gullen, &, Ryu, 2017). Therefore, estimating VKT in developing countries is much more beneficial in many areas which bears a considerable contribution for local economies. PKT always represents a person, where all trip information of a passenger/non-driver can be taken into account with public transport modes and, non-motorized transport modes. For a developing country or, for a rural area or, for a suburb, PKT tends to be higher. For assessing the usage of public transport modes of a community among different socio demographic groups, PKT can effectively be used. Also, to examine the daily mobility that combines both number and length of trips, PKT can be used as a standard measure. Therefore, PKT would be a representative measure of individuals in developing countries, where the majority uses public or non-motorized transport modes. This would be a reasonable indicator in transport planning and policy making activities in developing countries.

Factor	Sub Factor	Welch statistic	F Statistic for classical ANOVA	p	Level of Significance	F Critical	There is a significant difference among 3 areas (Yes/No)	Eta-Squared	Effect Size
Gender	Male	15.320	-	0.000	0.05	-	Yes	0.065	Medium
	Female	65.692	-	0.000	0.05	-	Yes	0.137	Large
Age (in years)	15-24	41.586	-	0.000	0.05	-	Yes	0.152	Large
	25-34	8.009	-	0.001	0.05	-	Yes	0.032	Medium
	35-44	8.210	-	0.001	0.05	-	Yes	0.052	Medium
	45-54	4.953	-	0.011	0.05	-	Yes	0.071	Medium
	55-69	14.721	-	0.000	0.05	-	Yes	0.197	Large
Employment Status	Employed	28.479	-	0.000	0.05	-	Yes	0.049	Medium
	Unemployed	47.099	-	0.000	0.05	-	Yes	0.145	Large
Residential Area	Urban	30.730	-	0.000	0.05	-	Yes	0.136	Large
	Rural	39.767	-	0.000	0.05	-	Yes	0.053	Medium
Income (In thousands LKR per month)	<25	-	4.585	0.011	0.05	3.07	Yes	0.043	Medium
	25-50	12.630	-	0.000	0.05	-	Yes	0.028	Small
	50-75	4.257	-	0.016	0.05	-	Yes	0.028	Small
	75-100	0.391	-	0.679	0.05	-	No	0.008	Small
	100-125	-	0.948	0.391	0.05	3.15	No	0.019	Small

Table 5. Statistically significant differences across three regions at  $\alpha = 0.05$

Factor	Sub Factor	p value from Post Hoc test			Comments
		East-South	South-North	East-North	
Gender	Male	0.000	0.000	0.801	East-South and South-North were statistically significantly different
	Female	0.000	0.930	0.000	East-South and East-North were statistically significantly different
Employment Status	Employed	0.000	0.803	0.000	East-South and East-North were statistically significantly different
	Unemployed	0.000	0.039	0.021	East-South, East-North and South-North were statistically significantly different
Residential Area	Urban	0.000	0.004	0.108	East-South and South-North were statistically significantly different
	Rural	0.000	0.488	0.000	East-South and East-North were statistically significantly different
Age (in years)	15-24	0.000	0.000	0.073	East-South and South-North were statistically significantly different
	25-34	0.005	0.985	0.018	East-South and East-North were statistically significantly different
	35-44	0.011	0.832	0.013	East-South and East-North were statistically significantly different
	45-54	0.050	0.709	0.076	East-South was statistically significantly different
	55-69	0.000	0.794	0.107	East-South was statistically significantly different
Income (In thousands LKR per month)	<25	0.083	0.049	0.489	South - North was statistically significantly different
	25-50	0.000	0.726	0.008	East-South and East-North were statistically significantly different
	50-75	0.118	0.571	0.027	East-North was statistically significantly different

Table 6. Identification of areas caused significant differences in VKT.

## 5. CONCLUSIONS

A questionnaire – based household survey was proposed for collecting data necessary for timely estimation of VKT/PKT in developing countries. A case study was conducted in three different areas of Sri Lanka. The study investigated VKT and PKT distribution over selected socio demographic factors such as gender, age, employment status, residential area, and income. Also, the proposed method aimed at collecting modes of travel data of people. A questionnaire was developed in order to collect trip distances, travel modes, number of passengers travelled and, socio demographic features of the respondents. 410, 224 and 330 respondents participated in surveys in each area respectively. Car, van, jeep, motor bicycle, three-wheeler and, foot-bicycle were observed to be popular travelling modes among people. The most frequent travel modes were found to be vans in Southern area and, motor bicycles in Northern and Eastern areas. The highest VKT was reported for a rural person in Eastern area and, the highest PKT was reported for a person with an income of 50-75 000 LKR in Southern area.

Specially, in this household survey method, respondents have to recall their trip information. Therefore, it is more beneficial to conduct face to face interviews rather than distributing questionnaires. In addition, if the number of socio demographic factors could be increased and, the study could be expanded to the entire country, that will improve the accuracy of the average VKT/PKT estimation for a person in Sri Lanka. As this method has the benefits of providing VKT and PKT estimates together with socio demographic and travel mode related information, the method can be recommended for replicating in other developing countries as well.

However, the implementation of a household travel survey may still seem challengeable in developing countries due to many reasons. Usually in countries like Sri Lanka, population and census surveys are conducted in a low frequency; such as once every 10 years. Therefore, the public is not aware of these kinds of surveys much and, the value of national surveys is not specifically discussed. However, regional wise annual agricultural surveys on crops production, population surveys etc. are conducted by state agents who are assigned for each region for such duties. For implementing and conducting this proposed household survey with higher response rates, the public can be reached through those state agents. Regional surveys may work better instead of a one-time national survey, which will consume higher cost. However, implementation of this methodology requires the engagement of a relevant state agency. Similar kind of situation may be expected from other developing countries as well, the implementation of this methodology will be easier with regional surveys that can be aggregated to the national level later on. More importantly, data can be stored in a database. The system monitoring and updating can be carried out by the same relevant agency that conducts surveys. The data could be made available for relevant transportation planning and management activities, transportation policy making, resource allocations and calculating emissions, energy consumption, and many other areas of developing countries. Another challenge that can be expected during surveys is, the accuracy of information provided by the respondents. It is recommended to conduct face to face shorter interviews rather than distributing and collecting questionnaires back. Asking questions and noting down the answers by the interviewer himself will be more effective in this method. Overall, it can be concluded that, this study showed the experience and the challenges faced during the proposed household VKT survey in Sri Lanka. This can serve as a guide for estimating VKT and PKT in other developing countries, which have similar conditions.

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