

## Urban sprawl measurement with use of VMT pattern: A longitudinal method in case of Famagusta

Kamyar Fuladlu<sup>1,2,\*</sup><sup>1</sup>Faculty of Architecture, Department of Architecture, Eastern Mediterranean University, Famagusta, Northern Cyprus<sup>2</sup>Faculty of Architecture, Department of Architecture, Near East University, Nicosia, Northern Cyprus

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### ABSTRACT

The sprawl as a result of rapid population growth appears when the city expands unplanned in the form of low-density development. The urban sprawl increase auto-dependency and Vehicle Miles Traveled (VMT) because sprawl is a single-use and low-density development. Therefore, measuring urban sprawl is vital, since planners get the benefit of this measurement to curb future unplanned developments. The current study aims to measure sprawl with the VMT pattern. Accordingly, the non-traffic method provides a practical solution for estimating the annual VMT in the case of Famagusta. Secondly, the build-density calculated using Google™ Earth and Geographical Information System. Finally, the VMT will be coupling with build-density for measuring the urban sprawl. The current study in compared to the similar kinds has the following advantages: a) current method can be performed in case of developing countries; b) this method is independent of traffic odometers, high-resolution census data, and land-use maps; and c) current method able to measuring the urban sprawl together with pattern of accessibility.

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### 1. Introduction

Urbanization is a multidimensional socio-economic process. Urbanization transfers the natural environment to the built environment. Urbanization converts formerly rural into urban settlements and results in the relocation of a population from rural to urban areas. According to the United Nations estimation, by 2050, roughly two-thirds of the world population will be living in the urban area. A well-managed within the urbanization process may result in maximize the profits of agglomeration with minimizing environmental degradation. Unlike unmanaged urban expansion, together with unsustainable and consumption patterns, resulting in urban sprawl and environmental degradation (UNDESA, 2019).

In most developing countries, unplanned expansion results in low-density development, which is creeping beyond the city boundary, while jobs still tend to stay in the core of the urban area.

But the invention of the horseless carriage made long-distance travel practical, auto-dependency made urban sprawl practical (Nechyba and Walsh, 2004) and realized the suburbia dream. Most of the studies are point out that there is a potential for a causal relationship between travel behavior and urban form. Likewise, the urban agglomeration intensification is associated with reducing auto-dependency (Beattie and Haarhoff, 2018; Boarnet and Crane, 2001; Williams et al., 2000). Segregation of the town elements and land-uses forces town residence to travel a long distance for their daily life. This is an unsustainable form of development and known as urban sprawl (Samarüütel et al., 2010; Williams et al., 2000). Similarly, Frumkin et al. (2004) believed “urban form refers to the amalgamation of individual elements of the towns and cities in which we live, work, play, and travel.” However, sprawl contradicts this idea since sprawl is a single-use form of development (Frumkin et al., 2004).

Urban sprawl is a particular form of suburban development (Behan et al., 2008; Downs, 1999). The urban sprawl perceives as a multidimensional phenomenon (Galster et al., 2001; Hamidi et al., 2015; Torrens, 2008). A rapid and uncontrolled growth in the urban population mostly results in urban sprawl (Bhatta, 2010). Urban sprawl increases the auto-dependency whereas the compact

\* Corresponding Author.

Email Address: [kamyar\\_fuladlu@yahoo.com](mailto:kamyar_fuladlu@yahoo.com)<https://doi.org/10.21833/ijaas.2020.05.003>

Corresponding author's ORCID profile:

<https://orcid.org/0000-0001-9988-742X>

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development is mainly pedestrian-friendly (Behan et al., 2008; Boarnet and Crane, 2001; Fuladlu, 2019; Fuladlu et al., 2018; Galster et al., 2001; Yeo et al., 2015). Because urban sprawl is a single-use development since the residents have to expend plenty of time to travel where they live, work, and play. Moreover, the majority of these travel done by single-occupant drivers, which increase traffic congestion in the urban area (Duany et al., 2000; Morris, 2005; Samarüütel et al., 2010). Likewise, urban sprawl increased the Vehicle Miles Traveled (VMT) (Behan et al., 2008).

The VMT is an indicator for measuring the total miles traveled by all vehicles on the network. The VMT provides an essential base to observe the auto-dependency, increasing the auto-dependency stands for rising the VMT. There are two methods for estimation of the VMT; a) traffic bases with use of odometer reading and traffic counts, b) non-traffic bases with use of household surveys, and fuel consumption (Kumapley and Fricker, 1996; Leduc, 2008). Since VMT is an indicator of the auto-dependency, therefore it can be used to measuring the urban sprawl. Because auto-dependency increases where urban development becomes sprawled. However, unlike the developed countries, the majority of developing countries are limited in the census and high-resolution data. Therefore, studies on VMT, auto-dependency, and accessibility remain unsolved in the case of developing countries.

According to the given introduction, the current study firstly aims to provide a practical solution for

estimating the annual VMT in the case of Famagusta as a developing country. Secondly, the estimate VMT will be used for measuring the urban sprawl in the case of Famagusta. Besides, the following objectives will be addressed during this study:

- Estimating the VMT with the use of the non-traffic method.
- Measuring the build-density with the use of Google™ Earth.
- Quantifying the measured build-density with the use of Geographical Information System (GIS).
- Comparing the build-density and the estimated VMT.

## 2. Material and method

The current longitudinal study tries to offer a practical approach for estimating the VMT. Besides, the estimated VMT will be used as an indicator for measuring the urban sprawl in the case of Famagusta. The study method, with the use of Google™ Earth, GIS, and various statistical approaches, tries to provide a beneficial method to estimate the VMT and measuring urban sprawl. The method will be addressed the main aims and objectives, which was to offer a non-traffic estimation in the case of developing countries. Accordingly, the study methodology is charted in Fig. 1.

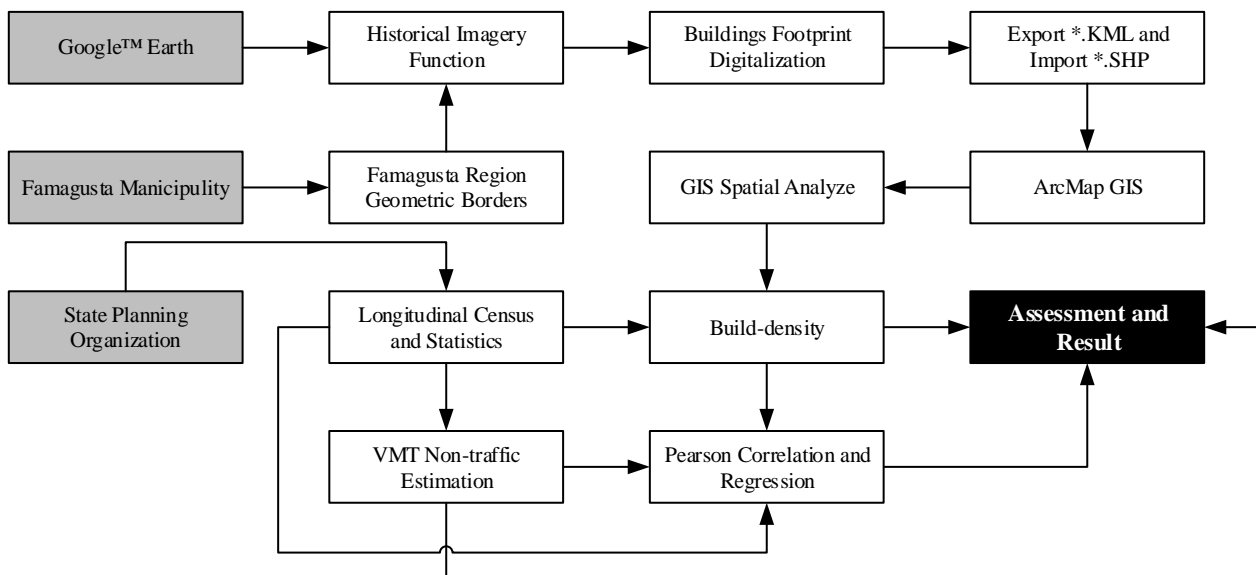


Fig. 1: Methodology diagram

### 2.1. Study area

Famagusta located at 35°07'30"N and 33°56'30"E is a city on the eastern coast of Cyprus. According to the SPO (2013), Famagusta had a 40,920 (de-jure) population in 2011. Famagusta has a specific situation due to the geographical location, harbor, historical castle, university, and uninhabited Varosha neighborhood (Önal et al., 1999). Since the 1974

conflict, the Varosha neighborhood becomes uninhabited. Therefore, later urban development continued in the opposite direction of the Varosha. Almost for the past half-century, real estate companies have been investing in mass housing projects in Northern Cyprus (Yorucu and Keles, 2007). These developments mainly located along the Mediterranean coastline and across the main arteries towards the suburban. This phenomenon is

seen in the case of Nicosia, Kyrenia, Trikomo, Morphou, and Lefka too (Hoşkara et al., 2009).

In the case of Famagusta, the majority of construction observed along the main arteries toward the Nicosia (capital city) and along the coastline toward the Trikomo. Besides the geographical location of the Famagusta, the role of the university and edu-tourism investment (Abubakar et al., 2014) significantly contribute to the mass housing development. According to the SPO (1999, 2007, 2013) Famagusta population during the current studied period (i.e., 2003-2016), 47.53% increased, which is a significant growth rate for a small area like the Famagusta. The main reasons could be addressed to the 1974 Cyprus conflict, and other factors include: a) the rapid population growth was on the northern government's agenda; b) extensive investment for the edu-tourism (Abubakar et al., 2014; Katircioğlu, 2014), c) enactment of the United Nations peace plan (Yorucu and Keles, 2007), and d) policy for attracting capital through the granting of residence permits to foreigners. The result is seen in the rapid population growth and accordingly, rapid urbanization in the northern part of the island.

## 2.2. Dataset preparation

This section includes two important parts, firstly gathering the required statistics and census data for

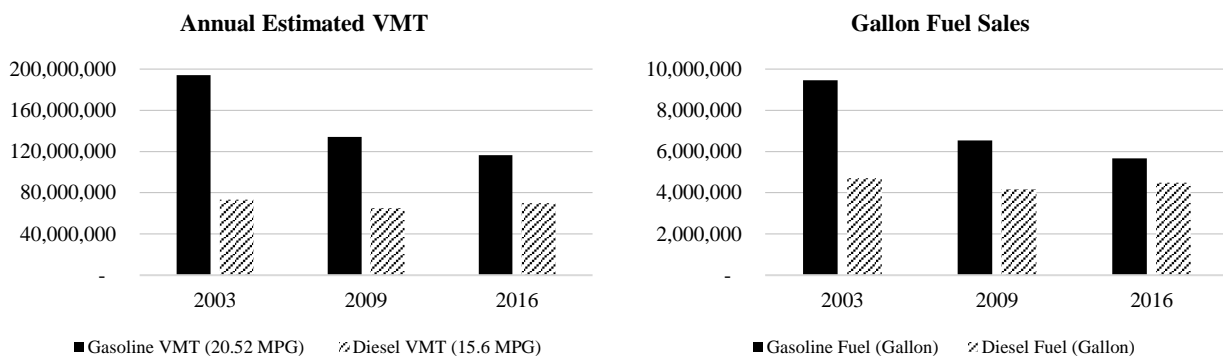


Fig. 2: Annual estimated VMT and gallon fuel sales

The fleet mile driven influenced by the number of driver-license and license-plate (Choo et al., 2005). Besides, increasing the VMT stands for increasing fuel consumption (Salon et al., 2012). Likewise, increasing the amount of VMT results in the automobile-crash, which is associated with traffic injuries and fatalities too (Ewing et al., 2014; Salon et al., 2012; Yeo et al., 2015). Accordingly, the comparison between these factors and the estimated VMT could be proved the process accuracy. The SPO (1998, 2005, 2011, 2016) dataset was used for gathering the required factors (Fig. 3).

The SPSS program was used to figure out the correlation between the annual estimated VMT, the number of license-plate, driver-license, fuel consumption, traffic accident, the number of injuries, and fatalities. Accordingly, a two-tailed Pearson

estimating the VMT. Secondly, the build-density will be calculated using Google™ Earth and GIS. These two parts will be used for the urban sprawl measurement.

### 2.2.1. The annual VMT estimation

The annual VMT (Eq. 1) will be estimated with the use of the fuel sales approach. This is one of the earliest methods which still known useful. The advantage of this method includes, firstly, TM can be estimated annually, and secondly, there is no need to travel on the roads (Azevedo and Cardoso, 2009).

$$A_{VMT} = T_{Gallon} \times T_{fleet}, \quad (1)$$

where  $A_{VMT}$  is the annual VMT;  $T_{Gallon}$  is the total gallon fuel sold (gasoline and diesel);  $T_{fleet}$  is the total fleet mile drive per gallon.

The total gallon fuel sales will be obtained from the SPO (1998, 2005, 2011, 2016). However, there is no record for the total fleet miles driven per gallon in Northern Cyprus. According to the Kitsios et al. (2015) study in the case of Cyprus, the average fuel efficiency for the gasoline engine vehicle is 20.52 Mpg, and 15.60 Mpg for the diesel engine vehicle. Therefore, the annual VMT accordingly estimated and the result exposed as the Fig. 2.

correlation was performed between the factors and results exposed in Table 1.

### 2.2.2. Build-density calculation

The build-density is a substantial character of urban sprawl (Downs, 1999; Ewing, 1997; Galster et al., 2001; Hamidi et al., 2015; Torrens, 2008). Build-density represents the proportion between the population and the rate of development for the same area (Frenkel and Ashkenazi, 2008; Galster et al., 2001; Shahraki et al., 2011). Since the study area relatively small and limited to the land-use maps, the following procedure was implemented based on the use of Google™ Earth. The historical imagery function of Google™ Earth provides a set of longitudinal rasters over the interest region.

Accordingly, the available interval of the program for the study area was 22<sup>nd</sup> of September 2003 and 24<sup>th</sup> April 2016. The Placemark tool in Google™ Earth was used for digitizing the footprints of the buildings as a

point feature. During the screen digitalization, 5,655 footprints for 2003 and 7,431 for 2016 were digitalized over the Famagusta.

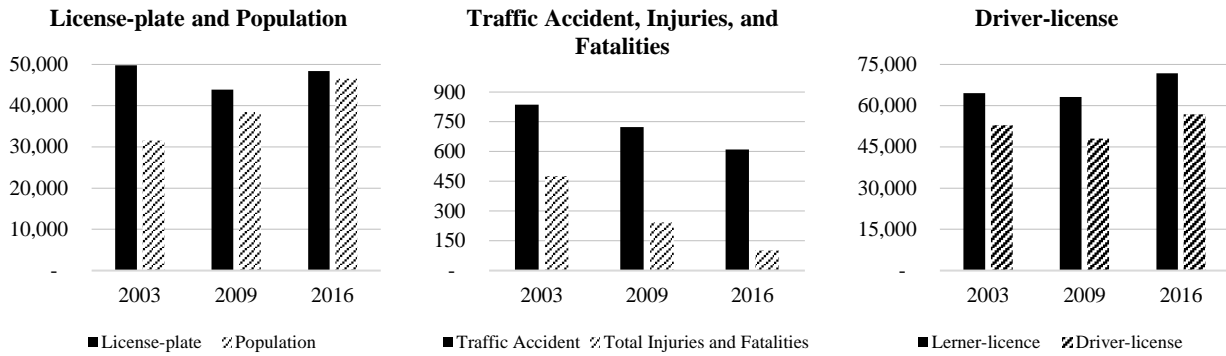


Fig. 3: License-plate, population, traffic accident injuries, fatalities, and driver-license

Table 1: Correlation between the estimated VMT and other factors

		License-plate	Driver-license	Learner-license	Diesel (Gallon)	Gasoline (Gallon)	Traffic Accident	Injuries and Fatalities
Gasoline VMT (20.52 MPG)	Pearson Correlation	0.504	-0.166	-0.557	-	1.000	0.953	0.987
	Sig. (2-tailed)	0.604	0.894	0.624	-	0.000	0.196	0.103
Diesel VMT (15.6 MPG)	Pearson Correlation	0.979	0.624	0.247	1.000	-	0.411	0.539
	Sig. (2-tailed)	0.129	0.571	0.841	0.000	-	0.731	0.638

The buildings footprints with a KML extension import to the GIS. To minimize the distortion, the whole dataset projected to the WGS1984 UTM Zone 36 North coordinate. The point density function in the GIS will be used to analyses the points density and develop the heatmaps. The point density used a kernel function to convert the discrete data to the continuous data (Longley et al., 2005) within the study boundary. The Famagusta geometric boundary was used to define the output extend. Accordingly, the geometry area is about 66.87 km<sup>2</sup> (the

uninhabited Varosha neighborhoods with 6.30 km<sup>2</sup> area were excluded from the geometry boundary). The 25 m cell size with the 500 m search radius experimentally choose for the kernel function. The output classified with the use of Jenks' natural break method. Four build-density classifications of open space, low-intensity urban, medium-intensity urban, and high-intensity (Wang et al., 2019) used for the Jenks' natural break function and result exposed as Fig. 4.

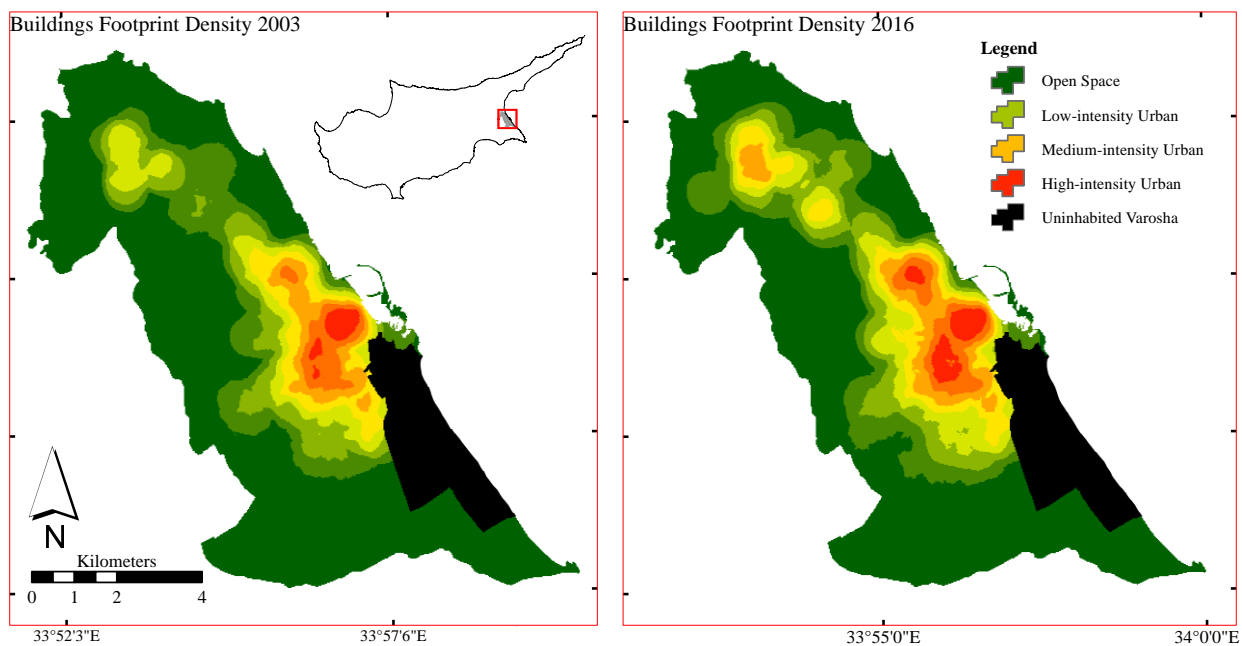


Fig. 4: Points density for 2003 and 2016

The urban area is calculated based on Fig. 4, and the results are exposed in Table 2. Due to a lack of historical imagery for 2009, the number of urban cells will be estimated with the use of the logarithmic regression. Since the estimation bases are two-point, always the R and R square of the model significant.

The estimated parameter for the model includes; constant equal to -1896364.46 and B value equal to 250104.59. Finally, the number of urban cells for each year is listed in Table 2. The build-density of the Famagusta will be calculated according to the urban area and population.

**Table 2:** Number of urban cell and build-density

Interval	Number of urban cells	Urban area m <sup>2</sup>	Population	Build-density	Gasoline VMT (20.52 MPG)	Diesel VMT (15.6 MPG)
2003	5,031	3,144,375	31,533	0.0100	194,104,773	73,294,928
2009	5,779	3,611,875	38,462	0.0106	134,270,603	65,240,328
2016	6,649	4,155,625	46,521	0.0112	116,344,104	69,929,149

The SPSS will be used to figure out the correlation between the annual estimated VMT, the number of urban cells, urban area, population, and build-

density. Accordingly, a two-tailed Pearson correlation was performed between the factors, and results are exposed in Table 3.

**Table 3:** Correlation between the estimated VMT and build-density

		Number of urban cells	Urban area m <sup>2</sup>	Population	Build-density
Gasoline VMT (20.52 MPG)	Pearson Correlation	-0.941	-0.941	-0.941	-0.955
	Sig. (2-tailed)	0.220	0.220	0.220	0.192
Diesel VMT (15.6 MPG)	Pearson Correlation	-0.376	-0.376	-0.376	-0.416
	Sig. (2-tailed)	0.755	0.755	0.755	0.727

### 2.3. Study assessment and result

The non-traffic method estimates the annual VMT for the Famagusta. According to Fig. 3, the amount of consumed gasoline decreased within the thirteen years, about -40.06 percent. In this sense, the consumed gasoline decreased by -30.83 percent from 2003 to 2009, and -13.35 percent decrease from 2009 to 2016. The condition of the consumed diesel is a bit different. The amount of consumed diesel decreased by -10.99 percent from 2003 to 2009, whereas from 2009 to 2016 increased by 7.19 percent. Since the method of VMT estimation is non-traffic, therefore the consumed fuel amount directly affects the estimated VMT. Accordingly, the overall amount of gasoline VMT decreased by -40.06 percent, and diesel VMT decreased by -4.59 percent. The number of traffic accidents within the thirteen years decreased by -27.03 percent. Likewise, the traffic accident decreased by -13.40 from 2003 to 2009 percent, and -15.75 percent decrease from 2009 to 2016. The number of injuries and fatalities within the thirteen years decreased by -78.78 percent. In this sense, the number of injuries and fatalities decreased by -48.99 percent from 2003 to 2009, and -58.44 percent decrease from 2009 to 2016.

According to Fig. 3, the amount of the issued license-plate within the thirteen years decreased by -2.78 percent. The issued license-plate decreased by -11.88 percent from 2003 to 2009, whereas from 2009 to 2016 increased by 10.32 percent. Unlike, the amount of the issued driver-license and learner-license increased by 7.62 and 11.09 percent within the thirteen years. In this sense, the amount of the issued driver-license and learner-license decrease by -9.23 and -2.20 percent from 2003 to 2009. While the amount of the issued driver-license and learner-license increased 18.56 and 13.59 percent from 2009 to 2016. Based on the Pearson correlation (Table 1) no significant correlations found between the

estimated VMT and other factors. Accordingly, the correlation between the estimated gasoline VMT and other factors was as follows: The license-plate R=0.504, driver-license R=-0.166, learner-license R=-0.557, traffic accident R=0.953, and total injuries and fatalities R=0.987. Similarly, the correlation between the estimated diesel VMT and other factors was as follows: The license-plate R=0.979, driver-license R=0.624, learner-license R=0.247, traffic accident R=0.411, and total injuries and fatalities R=0.539.

According to Table 2 and Fig. 4, the urban area increased within the thirteen years by 32.16 percent. The urban area increased by 14.87 percent from 2003 to 2009, and a 15.05 percent increase from 2009 to 2016. Likewise, the population increased within the thirteen years by 47.53 percent. The population increased by 21.97 percent from 2003 to 2009, and a 20.95 percent increase from 2009 to 2016. Unlike, the build-density increased within the thirteen years by 12.00 percent. The build-density increased by 6.00 percent from 2003 to 2009, and a 5.66 percent increase from 2009 to 2016. According to the Pearson correlation (Table 3), significant correlations found between the estimated VMT and number of urban cells, urban area, population, and build-density. Likewise, the correlation between the estimated gasoline VMT and other factors was as follows: The number of urban cells R=-0.941, urban area R=-0.941, population R=-0.941, and build-density R=-0.955. Similarly, the correlation between the estimated diesel VMT and other factors was as follows: The number of urban cells R=-0.376, urban area R=-0.376, population R=-0.376, and build-density R=-0.416.

### 3. Discussion

The current study provides a practical solution for estimating the non-traffic VMT in the case of Famagusta. Accordingly, the estimate VMT will be used for measuring the urban sprawl in the case of

the studied area. According to the study's assessment, VMT and fuel consumption have decreased in the last thirteen years. Likewise, the decline in VMT results in a reduction in traffic accidents, injuries, and fatalities over the same period. Although the issued license-plate has declined over the past thirteen years, the percentage has not been proportional to the decline of VMT, traffic accidents, injuries, and fatalities. The correlation result between the factors is strong (Table 1), but not significant at two-tailed due to the limited sample. Accordingly, there is a strong positive correlation between the gasoline VMT, traffic accident ( $R=0.953$ ), and total injuries and fatalities ( $R=0.987$ ). There are conflicts between the issued driver-license, learner-license, license-plate, and estimated VMT. Since the issued driver-license and learner-license, unlike the estimated VMT and license-plate increased within the last thirteen years. This could be addressed to the decline of auto-dependency and decreased of urban sprawl.

Based on the study's assessment, the urban development of the Famagusta within thirteen years gradually increased. Famagusta rapid population growth has resulted in the acceleration of urban growth during this period. The population growth was proportionally more than the urban growth, which results in increasing the build-density of the Famagusta. The increasing Famagusta build-density may result in decreasing the VMT and auto-dependency. Accordingly, the negative correlation between build-density and gasoline VMT ( $R=-0.955$ ) confirms the decrease of VMT an increase in build-density. The study finding is parallel with the work of other scholars (Glaeser and Kahn, 2004; Jackson, 1985; Mandal and Byrd, 2017; Nechyba and Walsh, 2004; Osborn, 1965; Yeo et al., 2015), which is proved the role of auto-dependency on the urban sprawl. Likewise, increasing the auto-dependency resulted in future consequences such as increasing CO<sub>2</sub> emissions, fuel consumption, VMT, traffic congestion, and automobile crash.

The current study is practical for estimating the VMT and measuring the urban sprawl in the case of developing countries, which are limited to the traffic odometers, high-resolution census data, and land-use maps. There are many studies in similar kinds (Ewing et al., 2014; 2003; Schimek, 1996) which are reputable. However, besides dependency on the high-resolution dataset, used different metrics, structural equation modeling, and principal component analysis, which made them complex. Unlike the current method easy to perform for estimating the VMT and measuring the urban sprawl. Undoubtedly, future studies should be conducted using GIS, remote sensing, landscape ecology indices, and multiple centrality assessment, especially in developing countries like Famagusta.

#### 4. Conclusion

The current study with the use of a longitudinal method offers a practical model for estimating the

VMT. Besides, this study used the VMT as an indicator for measuring the urban sprawl in the case of Famagusta. This study estimated the VMT and compared it with other factors includes license-plate, driver-license, learner-licenses, consumed fuel, traffic accident, injuries, and fatalities. The outcomes confirm VMT's decline in the last thirteen years. Likewise, VMT decline stands for the decrease of the auto-dependency, which affects to decrease in traffic accidents, injuries, and fatalities.

The current study calculates build-density using Google™ Earth and GIS. Accordingly, the build-density calculates using the historical imagery function of Google™ Earth. The footprint of the buildings in Famagusta gradually expanded from 2003 to 2016, which is to prove the rapid urban growth of the Famagusta. Since the population growth rate was bigger than urban growth. Therefore, build-density proportionally increased. Besides, the decrease of the VMT will be proved with the increase of the build-density within the last thirteen years.

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#### Compliance with ethical standards

#### Conflict of interest

The authors declare that they have no conflict of interest.

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