Can freeway traffic volume information facilitate urban accessibility assessment?  
Case study of the city of St. Louis

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A R T I C L E   I N F O

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A B S T R A C T

In urban contexts, accessibility measures are often utilized to represent the interactions among land use, transport and people’s trips to services and other facilities. Accessibility is generally evaluated using conventional traffic measures such as travel time and distance, but traffic volume, which is a product of the travel trips induced by people’s needs, may also be positively related to accessibility. This study tests the hypothesis “can freeway traffic volume information facilitate urban accessibility assessment?” Traffic volume based accessibility models are proposed to investigate this relationship and test the hypothesis. The results indicate that the answer to this question is a qualified “yes”, as there is a statistically significant relationship between traffic volume differences and accessibility. The coefficients of the models can potentially be used as a reference to guide the urban planning process. The limitations of the proposed models can be addressed by deploying Intelligent Transportation Systems (ITS) traffic sensors on ramps and arterial roadways.

1. Introduction

Accessibility, in an urban context, generally refers to the relationships among land use, transportation development and people’s ability to travel to different locations to gain access to services and facility opportunities (Helling, 1998). Páez et al. (2012) argued that accessibility has value as a tool in urban planning, where it can be used to identify connections between transportation and land use. Levine et al. (2009) stated that “accessibility outcomes are related to urban form” (p. 1) and went on to suggest that accessibility is more pertinent than mobility when seeking to interpret transportation demand.

Many perspectives and measures have been proposed to evaluate accessibility (e.g. Dong et al., 2006; Handy and Niemeier, 1997; Kwan et al., 2003; Neutens et al., 2010; Páez et al., 2012). A common distinction in perspectives is between place and person based, and each is applicable to specific scenarios. Measures associated with the place-based perspective include isochrone and gravity-based measures as well as those based on location modes; time-geographic and utility-based accessibility measures exemplify the person-based perspective. For example, travel time to work, which is an isochrone accessibility measure, has been factored into the national transport model in order to evaluate the Dutch National Transport Policy (Geurs and van Wee, 2004). This has also been selected as a measure in job accessibility related research; Ilhanfeldt (1993) investigated the relationship between job accessibility and Hispanic youth employment rates by extracting socio-economic data such as racial group and school enrollment status and travel time from home to job opportunity locations from the Public Use Microdata Sample (PUMS) of the 1980 U.S. Census of Population. Similarly, public transport travel time and actual walking distance were chosen as measures of accessibility for basic community services in a study by Yigitcanlar et al. (2007), who used a Geographic Information System (GIS)-based network to compute actual walking distances and derived the public transport travel time from the schedules published for public transport systems. Adopting the perspective of the ease of accessing opportunities, all of these studies focused on using travel time or distance in a GIS environment to evaluate various types of opportunities or specific service facilities in order to measure accessibility.

Ease of access to health care facilities is another important aspect of accessibility. Horner and Mascarenhas (2007) used the...
number of dentist locations in Ohio to identify potential issues with accessibility to dental services using census data and a dentist-related information database. Similarly, Apparicio et al. (2008) conducted a sensitivity analysis to compare differences in urban health service accessibility using travel time and distance as the accessibility measures. In this study, census data retrieved from Quebec’s Ministry of Health and Social Services website and the shortest network time, computed using GIS techniques, rather than actual travel times, were used for the sensitivity analysis. In an alternative approach, the use of place rank as an accessibility measure was proposed by El-Geneidy and Levinson (2011), who constructed a flow-based measure using origin–destination trip information and then applied their proposed accessibility measure to three cases using a combination of U.S. Census Bureau data, Canadian Census data and a health care provider database, noting that comprehensive travel data surveys can be used to generate place ranking information for a wide range of purposes.

A number of studies, including those described above, have used traffic operation performance measures such as average travel time and travel speed as accessibility measures to investigate the interaction between transport systems and land use. The benefits of adopting this approach are clear, as these performance measures can be easily understood by both urban planning researchers and decision makers (Geurs and van Wee, 2004), although regardless of the potential end use of the traffic operations data, the data used to measure accessibility are mainly obtained through surveys or from censuses. When implementing accessibility measures such as utility-based measures, a regional travel demand model is frequently required to simulate these measures (El-Geneidy and Levinson, 2011), although Geurs and van Wee (2004) noted that performance information such as level of congestion and average travel speed may be either observed or simulated (see, for example, Dong et al., 2006). Handy and Clifton (2001) highlighted this issue of transportation data unavailability. Unlike the relatively high availability of transportation network files from official bodies such as the U.S. Census Bureau, transportation related characteristics such as travel time and travel cost cannot be flexibly accessed at the neighborhood level required to a useful analysis. As a result, most of the traffic operation performance measures currently utilized as accessibility measures are simulated rather than based on real traffic operation performance measures.

Since Intelligent Transportation Systems (ITS) facilities have begun to be widely deployed nation-wide in many countries, ITS data such as traffic sensor data and surveillance video footage can now be retrieved from most transportation management centers (TMC) at low or no cost. This increasing availability of traffic data opens up new opportunities for simplifying and reinforcing the process of accessibility evaluation. To the best of our knowledge, as yet there have been few investigations into the relationship between traffic volume and the level of accessibility. We therefore propose the following hypothesis: “Can freeway traffic volume facilitate urban accessibility assessment?” Instead of using conventional traffic operation performance measures as accessibility measures, this study links information on traffic volume with the accessibility of a “zone” (defined in Section 2.2 below). However, it is possible that fluctuations in freeway traffic volume may not accurately represent the inbound and outbound traffic for a particular zone and hence the traffic volume fluctuation of a zone may not actually be related to accessibility. The primary goal of this research was therefore to test the hypothesis by examining the relationship between traffic volume and facility opportunities using ITS sensor data and then incorporating facility opportunity data. One potential contribution of this study is to develop an effective traffic-volume-based measure with which to evaluate urban accessibility using the types of ITS data that are only rarely used by transportation planners at present. If this approach does indeed prove to be feasible, as yet unrecognized benefits of using the existing ITS data collection infrastructure may be revealed. For example, existing ITS data could be reused by transportation planners and the cost of transportation planning data collection could be reduced. Therefore, transportation planners may wish to consider utilizing this new approach to evaluate urban accessibility in place of traditional survey methods or census data.

The remainder of this paper is organized as follows. The next section will provide details of the assumptions supporting this research and present the new framework for using traffic operation data to measure accessibility. This is followed by a section describing the traffic sensor data used in this study and the related GIS analysis. The empirical results are presented next, and then discussed in the fifth section. The final section summarizes the study and its major findings and considers directions for future research.

2. Methodology for computing a traffic volume based accessibility measure

2.1. Underlying relationship between accessibility and facility opportunity

The terms “isochrone measure” and “cumulative opportunity measure” can be alternatively used to represent the number of facility opportunities that can be reached within a given travel cost (e.g. travel time and distance). The general form of an isochrone measure can be written as:

\[
\text{Accessibility}_i = W^T X
\]  

(1)

where \(\text{Accessibility}_i\) represents the accessibility of zone \(i\); \(T\) is the transpose symbol; \(W = [w_1, w_2, w_3, \ldots, w_n]^T\); \(w_i\) equals 1 if zone \(i\) can be reached within a given travel cost, but otherwise equals 0; \(X = [x_{11}, x_{12}, x_{13}, \ldots, x_{1n}]^T\); \(x_i\) means the number of facility opportunities within zone \(i\).

Eq. (1) indicates that \(\text{Accessibility}_i\), is proportional to \(X\), when \(W\) is fixed. This paper aims to test the hypothesis “Can freeway traffic volume information facilitate urban accessibility assessment?”. The answer will be positive if, and only if, traffic volume is proportional to \(X\). By considering the various types of facility opportunities, \(X\) can be written in a more general form. Equation (2) shows the \(X\) transformation, which indicates that the answer to the question posed above relies on the relationship between traffic volume and the number of facility opportunities by type.

\[
X = [x_{11}, x_{12}, x_{13}, \ldots, x_{1n}]^T
\]

(2)

where \(x_{ij}\) represents the number of Type \(j\) facility opportunities in zone \(i\). Two types of conditions can be used to determine the value of \(W\): (a) travel cost is given; (b) the zones are pre-defined. The next section will seek to determine the zones by introducing the concept of the Accessibility Evaluation Zone (AEZ).

2.2. Assumptions

Before developing a statistical model to utilize traffic volume information to measure accessibility, three major assumptions were identified and these are discussed in turn below.

2.2.1. The definition of Accessibility Evaluation Zone (AEZ)

In order to conduct a valid investigation of the relationship between the traffic volume collected from freeway sensors and
urban accessibility, the accessibility evaluation zones used in this study must spatially include at least one freeway segment, and at least one on-ramp and one off-ramp must be physically located on the bounded freeway segments, as ramps connect a freeway system to the surrounding urban areas and travelers are therefore assumed to access each zone via its associated freeway ramps.

2.2.2. A high-accessibility zone will attract more external trips

Fig. 1 illustrates this assumption:

(A) A greater number of facility opportunities will increase the level of accessibility of an accessibility evaluation zone. This is because the level of accessibility of an accessibility evaluation zone goes up as the number of facility opportunities increases if travelers’ time budgets are limited: the higher the level of accessibility of the accessibility evaluation zone, the more likely it is that travelers will be attracted into the zone as they can easily access several of the services provided by the higher density of facility opportunities in a relatively short period of time.

(B) In a high accessibility zone, trips generated from other zones will be attracted into this zone, meaning non-residents will tend to use the freeways to access this zone. Those living in the zone will also tend to stay there because of its better facility opportunities, resulting in a greater number of internal trips and fewer external trips. In contrast, in a zone with low accessibility, those residing in the zone will be more willing to travel outside to seek better or more facility opportunities, and the lack of facility opportunities means that few non-residents will choose to visit the zone.

2.2.3. Non-working trips could be used to reveal the level of accessibility

In order to reveal the level of accessibility from a traveler’s point of view, the time period selected is critical for any investigation of the relationship between traffic volume and accessibility. It is generally accepted that weekday traffic flow patterns are relatively stable, because weekday traffic is mainly comprised of work-based trips. Travelers’ “willingness to travel” is therefore not fully reflected on weekdays as it refers to non-working trips, most of which are concentrated in particular time periods such as weekends. Therefore, weekends are generally selected as the most appropriate time periods for studies in which the traffic volume produced by non-working trips is used to evaluate the level of accessibility.

2.3. Model formulation

Compared to traditional surveys of daily travel times, the proposed method could potentially reduce both data collection time and costs, in addition to providing a way to capture travelers’ perceptions. The new method proposed here is designed to identify the relationship between urban accessibility and the traffic volume fluctuations on freeways within a given zone. Since different opportunities are affected by different factors impacting attractiveness, various categories of opportunities have been factored in when establishing the proposed new measure based on traffic volume.

2.3.1. Inbound and outbound traffic volume

As mentioned above, the presence of greater facility opportunities in a zone should attract traffic from outside the zone and retain traffic from inside the zone. Hence, the higher the accessibility, the greater the volume of inbound traffic on the off-ramps and the lower the volume of outbound traffic using the on-ramps for a freeway segment within that zone for a given time period. This relationship between the inbound traffic and facility opportunities is formulated as Eq. (3). Conversely, where facility opportunities are few, outbound traffic shows a negative effect and the relationship between the outbound traffic and facility opportunities is formulated as Eq. (4):

\[
\begin{align*}
    v_{in,i} &= b_0 + b_nx_{n,i} + e_{in,i} \\
    v_{out,i} &= c_0 + c_nx_{n,i} + e_{out,i}
\end{align*}
\]

where

- \( v_{in,i} \) is the inbound traffic volume for all the off-ramps in zone \( i \) during the study time period;
- \( v_{out,i} \) is the outbound traffic volume for all the on-ramps in zone \( i \) during the study time period;
- \( x_{n,i} \) represents the number of non-work opportunities in Category \( n \) within zone \( i \);
- \( b/s \) and \( c/s \) are coefficients that must be calibrated; and
and \(e_{in,i}\) and \(e_{out,i}\) are error terms representing unobserved information and other observation errors.

In order to evaluate the combined accessibility resulting from all the facility opportunities, Eqs. (3) and (4) are linearly combined as Eq. (5).

\[
v_{in,i} - v_{out,i} = \beta_0 + \beta_{v}X_{in,i} + e_{in,i} = a_0 + \alpha_0X_{in,i} + e_i
\]

where \(\beta_0\) and \(\alpha_0\) are the residuals to be calibrated in the linear equation.

As Eq. (5) demonstrates, the difference between inbound and outbound traffic volume, \((v_{in,i} - v_{out,i})\) is assumed to be positively correlated with the accessibility.

2.3.2. Relationship between traffic volume difference and accessibility

Since only a few freeway ramps have traffic sensors installed, this study instead developed a way to estimate the traffic volume for on-ramps and off-ramps by using the data collected from traffic sensors located in the main freeway lanes.

Traffic volume differences between the inbound and outbound traffic on ramps can be estimated and calculated depending on the freeway ramp layout and the ITS sensor locations. Fig. 2 illustrates a traditional on-ramp/off-ramp freeway layout. Where ITS traffic sensors are installed on both the on- and off-ramps, traffic volume fluctuations are simply represented by differences in the on- and off-ramp traffic volumes. Where traffic sensors have not been installed on the ramps, traffic volume fluctuations can be estimated based on the mainline traffic volume. Fig. 2 shows an example where ITS traffic sensors are installed both upstream and downstream of the on- and off-ramp pair and represents the layout of the site chosen for this study.

The traffic volume collected at the start and end of segment \(i\) during the study period are denoted \(v_{s,i}\) and \(v_{e,i}\), respectively, as shown in Fig. 2. Eqs. (6) and (7) show the calculation of \(v_{s,i}\) and \(v_{e,i}\) using the traffic volume data collected from the sensors on the main lanes, and Eq. (8) shows the relationship of \(v_{s,i}\) and \(v_{e,i}\).

\[
v_{s,i} = \sum_i \sum_t v_{s,i}(t)
\]

\[
v_{e,i} = \sum_i \sum_t v_{e,i}(t)
\]

\[
v_{e,i} = v_{in,i} - v_{out,i}
\]

where

- \(v_{in,i}\) is the total volume at the start sensor group of freeway segment \(i\) during time period \(T\);
- \(v_{out,i}\) is the total volume at the end sensor group of freeway segment \(i\) during time period \(T\);
- \(v_{s,i}(t)\) is the volume traveling on lane \(l\) at the start sensor group of freeway segment \(i\) at time \(t\); and
- \(v_{e,i}(t)\) is the volume traveling on lane \(l\) at the end sensor group of freeway segment \(i\) at time \(t\).

Substituting Eqs. (9) into (5) gives:

\[
v_{s,i} - v_{e,i} = a_0 + \alpha_0X_{ini} + e_i
\]

2.3.3. Transformation

The value of \(v_{s,i} - v_{e,i}\) may vary considerably depending on the time of day and the location. Thus, \(v_{s,i} - v_{e,i}\) in Eq. (10) may have a large range of values, so it is helpful to transform the value of \(v_{s,i} - v_{e,i}\) into a reasonable range (e.g. from 0 to 1, or from 0 to 100) by using the inverse-logit function.

We therefore jointly applied the inverse-logit function (Ashton, 1972) and the Gaussian distribution model to the values of traffic volume difference. It should be noted that applying the transformation procedure to the original dataset does not change the characteristics (i.e. the trend within the dataset or the data relevance) of the dataset. Only the range of the traffic volume difference is altered to ensure the output can be more easily understood and interpreted.

\[
\logit^{-1}(x) = \frac{\exp(x)}{1 + \exp(x)}
\]

\[
x' = \frac{x - \mu}{\sigma}
\]

where \(x'\) is normalized \(x\) by \(\mu\) and \(\sigma\).

The model used to investigate the relationship between the traffic volume difference and urban accessibility proposed in this study based on freeway traffic volume data is expressed as Eq. (11). A conceptual “traffic volume based accessibility score” is proposed to help understand the relationship.

\[
\logit^{-1}\left(\frac{(v_{s,i} - v_{e,i}) - \mu}{\sigma}\right) = a_0 + \alpha_0X_{ini} + e_i
\]

where \(v_{s,i} - v_{e,i}\) represents the traffic volume difference;

\[
\logit^{-1}\left(\frac{(v_{s,i} - v_{e,i}) - \mu}{\sigma}\right)
\]

is the traffic volume based accessibility score;

- \(\alpha\) is a vector of parameters to be estimated;
- \(\mu\) is the average of \((v_{s,i} - v_{e,i})\);
- \(\sigma\) is the standard deviation of \((v_{s,i} - v_{e,i})\); and
- \(X_{ini}\) represents the number of facility opportunities in category \(n\) within zone \(i\).

3. Data collection

ITS sensors are fairly common along the roadways in many major cities in the U.S. Generally, the ITS sensors are installed every mile along freeway corridors. In this case study, the ITS data
The collected ITS data, including lane-by-lane volume, speed and occupancy, are aggregated into 30 s time periods. In order to examine the feasibility of the proposed method, the ITS data collected from a total of 43 pairs of two spatially consecutive traffic sensors on the mainline freeways within the city limits were used. Data for a total of 38 Saturdays was collected between June 11, 2012 and March 31, 2013 and used for the model calibration.

Besides the traffic data and facility data, the GIS-based neighborhood and characteristics data within the City of St. Louis were provided by EWG, the Metropolitan Planning Organization (MPO) for the Greater St. Louis area. Seventy-nine neighborhoods in the GIS-based data were pre-defined as traffic analysis zones (TAZ) by EWG. As these TAZs are relatively small and might not contain sufficient information to model the relationship of traffic volume and the accessibility of zones, the TAZs were further grouped into larger accessibility evaluation zones, as defined in the Assumptions above, for subsequent modeling and analysis. Fig. 4(a) shows the 79 original neighborhoods and 12 accessibility evaluation zones.

Nine categories of facility opportunities, namely food services, retail stores, education services, entertainment services, financial services, health facilities, outdoor facilities, living support services and public transportation services, were selected as factors for evaluating accessibility. These nine categories cover all the facility opportunities for non-work based trips. The first eight categories of opportunities utilized in the database are managed by Dun & Bradstreet (D&B) Inc. (Dun and Bradstreet, 2013), and provided by the East–West Gateway Council of Governments (EWG). This database contains over 213 million business service records. Each service in a specific category is associated with geo-coded location information and a corresponding North American Industry Classification System (NAICS) code. Public transportation information, specifically transit bus and Metrolink stop locations, were provided by Metro Transit – St. Louis. Fig. 4(b) and (c) show the spatial locations of facility opportunities and public transportation stops, respectively. Fig. 4(d) shows the spatial locations of ITS traffic sensors in the City of St. Louis.

3.1. Preliminary data analysis

3.1.1. Study time period selection

In order to select the most appropriate time period for capturing non-working trips on Saturdays, the traffic volumes collected from traffic sensors were averaged by time of day for the 38 Saturdays to identify the peak travel hours. A series of traffic hourly volume plots from the sensors on I-70, I-64, I-44 and I-50 revealed that the freeways consistently experienced a high volume of traffic for the time period from 10 am to 6 pm on Saturday. Consequently, we chose 10 am–3 pm as the study time period because the 3 pm–6 pm data is likely to consist of a higher number of returning-home trips than out-of-home trips. In this case, the accessibility evaluation would not be affected by returning-home trips.

3.1.2. Information extraction using spatial analysis

In order to select the most appropriate time period for capturing non-working trips on Saturdays, the traffic volumes collected from traffic sensors were averaged by time of day for the 38 Saturdays to identify the peak travel hours. A series of traffic hourly volume plots from the sensors on I-70, I-64, I-44 and I-50 revealed that the freeways consistently experienced a high volume of traffic for the time period from 10 am to 6 pm on Saturday. Consequently, we chose 10 am–3 pm as the study time period because the 3 pm–6 pm data is likely to consist of a higher number of returning-home trips than out-of-home trips. In this case, the accessibility evaluation would not be affected by returning-home trips.
an AEZ and the traffic volume data captured by selected traffic sensors was also utilized as the input for Eq. (11).

Table 1 summarizes the descriptive statistics for the number of facility opportunities for all 12 of the designated accessibility evaluation zones in the City of St. Louis. Facility opportunities associated with NAICS codes have been classified into 8 categories, each of which includes several collections of NAICS codes. For example, the category of “retail store” is comprised of 7 different NAICS codes. These statistics were used to describe the number of facility opportunities by NAICS code as follows: there are a total of 563 facility opportunities with the NAICS code 445 in the 12 accessibility evaluation zones, and the minimum, maximum, mean

Fig. 4. GIS-based data (a) The geo-coded data for 79 neighborhoods and 12 separate zones of interest (Zones 0 through 11). (b) The spatial distribution of Metro bus stops and Metrolink stations in the City of St. Louis. (c) The spatial distribution of business establishments in the City of St. Louis. (d) The spatial distribution of traffic sensors in the City of St. Louis.
value and standard deviation of the number of these facility opportunities in each zone are 22, 79, 46.9, and 18.2, respectively. The ninth type of facility opportunity considered in this study, public transportation services, is not included in this table.

4. Empirical analysis results

Before the modeling process could proceed, the relationship between each category of facility opportunities had to be investigated. As expected, the nine categories of facility opportunities all had positive effects on the traffic volume based accessibility score. The plots of the relationships between each category of opportunities and the traffic-volume-based accessibility score are shown in Fig. 6. The plots demonstrate that all the categories of facility opportunities have a positive correlation with the traffic volume based accessibility score.

Table 2 lists the 11 models calibrated. Models 1 to 9 are the linear models corresponding to Fig. 6(a–i), respectively. Model 10 contains all the variables for the nine categories. The variables for the categories of “Education”, “Healthcare”, “Living support”, “Retail store” and “Public transportation” are not significant. A test for multicollinearity was conducted to examine the collinear relationship among the variables. The results of the multi-collinearity test indicate that these five of the variables where significance was found are linearly correlated. In an effort to represent the traffic-volume-based accessibility score with fewer variables, Model 11 retains all the variables except for three insignificant categories (“Living support”, “Retail store” and “Public transportation”). Model 11 shows...
coefficients in both of these models can be used to indicate the total number of facility opportunities in a zone. Moreover, the models revealed slightly higher coefficients for facilities such as food service, supermarkets, and pharmacies compared to hospital services or jobs. A potential application of the calibrated model is that transportation planners will be able to prioritize transportation investments according to the coefficients of the models.

### 4.1. Discussion

Previous studies in this area generally looked at measuring accessibility for a single category of facility opportunity (e.g., health services or jobs) and revealed few hints of the relationship between traffic volume information and the level of accessibility. In this study, Models #1–9 are designed to investigate the relationships between the traffic volume and the number of facility opportunities in an accessibility evaluation zone by category. The results of the empirical analyses demonstrate that all of the relationships are positive, indicating that the scores computed from the traffic volume on freeways in each of the accessibility evaluation zones increase with increasing numbers of facility opportunities for all 9 of the categories. This indicates that traffic volume based accessibility score can serve as a useful alternative indicator of the number of facility opportunities for each of the categories. Since the number of facility opportunities in a zone are positively related to the accessibility of that zone, this implies that freeway traffic volume could serve as an alternative measure of accessibility for individual facility opportunities in the context of an urban environment.

An overall perspective on the relationship between the total number of facility opportunities for all 9 categories and traffic volume based accessibility scores can be developed by examining Models 10 and 11. These results again demonstrate that traffic volume based accessibility score can be used as an indicator of the total number of facility opportunities in a zone. Moreover, the coefficients in both of these models can be used to indicate whether a specific category of services could usefully be introduced into a zone and predict the impact of a new service on the zone’s transport system for future planning. For instance, if a city decided to improve the accessibility of a shrinking residential area in the center of the city, these models suggest that establishing living support services at current locations may be more beneficial than such placements in entertainment places. This is because the coefficients for entertainment services (0.181) were markedly higher than that of living support services (0.763). Thus, these models could be used as a tool to assist the decision making process by providing a reference to help determine which categories of facility opportunities need to be considered first. Combined with a cost-benefit analysis for each type of facility opportunity, decision makers would be able to identify the facility opportunities that would be most beneficial to that neighborhood.

The analysis results lead to a positive answer to the question “Can freeway traffic volume information facilitate urban accessibility assessment?” due to the strong relationships found to exist between (inbound/outbound) traffic volume and facility opportunities. However, the application of traffic volume based accessibility could be limited at present due to the existing geographical layout of ITS traffic sensors. Other limitations include:

1. **Unavailability of traffic sensors on ramps.** We had expected to utilize traffic volume data collected from sensors located on freeway on-ramps and off-ramps in this study to represent the inbound and outbound traffic volume, respectively, of each zone. However, due to the lack of traffic sensors on ramps, those located on the mainline of the freeways had to be used instead to estimate the inbound and outbound traffic volume. If more accurate data were collected for ramps equipped with traffic sensors, the resulting traffic volume based score is likely to provide a more accurate measure of accessibility.

2. **Selection of Accessibility Evaluation Zone (AEZ).** This study defined an AEZ as having at least one freeway segment crossing the AEZ. Based on this definition, the accessibility of a zone that is geographically close to a freeway can be evaluated. However, the study’s findings would not be applicable in the case of a zone that is some distance from a freeway. Moreover, in order to utilize the zone’s traffic volume data for both inbound and outbound vehicles, several ramps must be located in the zone. Thus, an AEZ must be large enough to satisfy these requirements, limiting the application of this study.

3. **The impact of highly congested traffic conditions.** Few instances of highly congested traffic conditions were...
observed on Saturdays in this study, but highly congested traffic will reduce the traffic volume on freeways, and this low traffic volume will in turn affect the model performance. A more refined study time period on Saturdays could overcome the limitation.

Many of these constraints will be resolved as more traffic sensors become available. ITS traffic sensors have recently begun to be more widely installed on freeways, providing significant benefits for transportation related agencies such as the Missouri Department of Transportation by enabling them to improve freeway

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Fig. 6. Plots of the linear regression model between each of the 9 categories of opportunities and traffic volume.
management and providing the public with better performance on measures such as travel times. Extending the installation of traffic sensors from the main freeways to arterial roadways, as well as on- and off-ramps, will also have a major impact on data availability. The wider introduction of traffic sensors performing functions such as traffic signal control and ramp metering shows great potential, with the focus beginning to shift from the perspective of traffic operation to long-term transportation planning.

5. Conclusions

Accessibility serves as an important indicator in both urban planning and transportation planning. The concept of accessibility encompasses both land use systems and transport systems and, based on different perspectives of accessibility, a number of measures for assessing accessibility have been built using various data sources. Most of the research related to measuring accessibility either utilizes and parses survey or census data directly, or converts the survey or census data to existing measures (e.g. average travel time) by applying travel demand models. This study instead adopted an innovative approach by using real-world traffic volume data retrieved from traffic sensors embedded in the freeways in the City of St. Louis to measure the accessibility of zones in urban areas, under the assumption that the difference between the inbound and outbound traffic volume of a zone is positively related to that zone’s accessibility. Due to the lack of appropriately located traffic sensors, rather than using the travel volume on the freeway ramps directly, for this study it was necessary to adopt an approach that involved estimating the inbound and outbound traffic volume by using data collected from traffic sensors embedded in the main carriageways of the freeways.

A traffic volume based accessibility score is proposed here to investigate the relationship and test the hypothesis “can freeway traffic volume facilitate urban accessibility assessment?” The results of the analysis revealed that the relationship between the scores and the numbers of facility opportunities by category in
each of the Accessibility Evaluation Zones is positive and the relationship between the scores and the linear combination of each category are statistically significant.

In practice, the traffic volume based accessibility score and the models discussed above could potentially be used as a reference to guide the urban planning process after some refinement and with further calibration and verification. Different categories of facility opportunities contribute different amounts to the level of accessibility of a zone. The coefficients in the models can reveal to urban and transportation planners the categories of facility opportunities that are likely to have relatively large impacts on measures of accessibility.

The major disadvantage of the traffic volume based accessibility score is the current lack of appropriately sited traffic sensors. The score and models proposed in this study can only be applied to a zone crossed by at least one freeway segment and the models require large zones to adequately measure accessibility. However, with the rapid development and wide deployment of traffic sensors, in the near future ramps and major arterial roadways will also incorporate traffic sensors. The resulting higher availability of traffic volume data will support the concepts proposed in this study.

Traffic volume is a product of the trips taken to meet people’s various needs. The authors believe that a straightforward approach of measuring accessibility in the context of urban and transport systems is to utilize traffic volume data. Future work will focus on validating and calibrating the model proposed in this study by collecting more traffic volume data from existing ITS traffic sensors. A sensitivity analysis will be conducted to identify differences in the traffic volume based accessibility score and other accessibility measures. The feasibility of the model transferability from non-work trips to work trips will also be considered.

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