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Profile-speed data-based models to estimate operating speeds for urban residential streets with a 30 km/h speed limit

Do Duy Dinh *, Hisashi Kubota

Graduate School of Science and Engineering, Saitama University, 255 Shimo-Okubo, Sakura-Ku, Saitama City, Saitama Prefecture, 338-8570, Japan

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ABSTRACT

A speed limit of 30 kilometres per hour (km/h) has been widely introduced for urban residential streets to ensure traffic safety and allow these streets to fulfil other intended functions. However, excessive speeds on these roads are very common, causing traffic safety problems and threatening the liveability of neighbourhoods. An effective and active way to deal with speeding is the application of a performance-based design approach, as mentioned in previous research. In a performance-based design approach, street geometrics and roadside elements are selected based on their influence on the desired driving speeds. The relationship between driving speeds and street features therefore needs to be determined. Although several studies have developed operating speed models for urban streets, all of these models were calibrated based on data for streets with speed limits of more than 30 km/h. The present research is designed to investigate the influence of various roadway and roadside characteristics on operating speeds on urban tangent street sections with a 30 km/h speed limit using profile-speed data. A simultaneous equation regression with a three-stage-least-square (3SLS) estimator was used for the modelling effort. The driving speed models developed in this study incorporate several street design factors, which provide helpful information for urban planners and street designers to cope with speeding issues on residential streets.

1. Introduction

Urban residential streets have the lowest ranking in terms of street function classification. In addition to having the primary function of providing access to adjacent buildings or land lots for all street users, residential streets are also usually used as spaces where local residents can congregate. In many cases, vulnerable residential-street users have to share the roadway with motorised vehicles, which puts them at high risk for an accident. In an attempt to create safer and more liveable neighbourhoods, a speed limit of 30 km/h has been widely introduced for the majority of residential streets. Previous studies have documented strong evidence supporting the safety benefits of setting the 30 km/h speed limit. A report by OECD/ECMT [1] highlighted that 90% of pedestrians hit by a car travelling at 30 km/h survived, while only 20% of pedestrians hit by a car travelling at 50 km/h survived. Rosén and Sander [2] concluded that the pedestrian fatality risk at 50 km/h was more than twice as high as the risk at 40 km/h and more than five times the risk at 30 km/h. Other studies found significant reductions in accident frequency and severity in neighbourhood streets after 30 km/h speed limits were installed [3,4].

Despite efforts to slow down motorised traffic on residential streets by setting the 30 km/h speed limit, excessive speeds on these roads are very common causing traffic safety problems and threatening the liveability of neighbourhoods. In Japan, the percentage of all traffic accidents occurring on residential streets in which most of them have a 30 km/h speed limit has increased to an unacceptably high 22.3% [5]. Passive measures have traditionally been used to deal with speeding in residential areas. For example, many localities have installed traffic calming measures such as speed humps. However, traffic calming can be costly, leading to limited application. In addition, some physical traffic calming tools may cause negative side effects such as noise, vibrations, driving discomfort, and unwanted visual intrusions. It is therefore necessary to find solutions that more actively and efficiently address the excessive-speed problem. Streets should ideally be planned and designed using the performance-based design approach suggested by a number of researchers to make them inherently calmer [6–8]. Under this procedure, the relationships between traffic speeds and street environments are employed to facilitate the selection of street layout and roadside elements to obtain the desired traffic result. However, operating speed models for each specific street environment are needed to execute performance-based design. Although several studies have developed operating speed models for urban streets, all of them were calibrated based on data for streets with speed limits of 40 km/h or

* Corresponding author. Tel./fax: +81 48 858 3554.
E-mail addresses: dinh@dp.civil.saitama-u.ac.jp (D.D. Dinh), hisashi@dp.civil.saitama-u.ac.jp (H. Kubota).
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more; these models therefore are not applicable for residential streets with a 30 km/h speed limit. This lack of applicable models prevents urban planners and street designers from applying the performance-based design approach to deal with speeding issue on urban residential streets.

2. Previous operating speed models for urban streets

While numerous operating speed models have been developed for rural highways [9,10], a relatively smaller number of studies have been completed for urban conditions. It is conceivable that urban streets have a more complex driving environment than most rural highways. Therefore, as expected the existing models for urban streets often included more speed-influencing factors than that for rural environment. In addition, vehicular speeds on urban streets have been investigated not only at horizontal and/or vertical curves as often seen in available models for rural highways but also at tangent sections.

There are several available operating-speed models developed for vertical/horizontal curves on urban/suburban streets. Fitzpatrick et al. [11] found that the inferred design speed was the only significant variable for predicting operating speed on crest vertical curves on suburban roadways. In the same study, the independent variables in the speed models for horizontal curves were curve radius and approach density. After evaluating the influence of geometric, roadside and traffic control device factors on operating speed on four-lane suburban arterials, Fitzpatrick et al. [12] stated that the posted speed limit was the most significant variable, while deflection angle and access density class were also significant predictors of operating speed on horizontal curves. The researchers also developed a speed model for horizontal curves without including a posted speed limit and found that the presence of medians and the type of roadside developments significantly influenced drivers' speed. The degree of curve was the only significant variable in the operating speed models for horizontal curves on urban collector streets developed using ordinary regression by Tarris et al. [13]. With the same data set, Poe and Mason [14] introduced a mixed-model approach to show that degree of curvature, longitudinal grade, lane width, and roadside characteristics were significant variables in operating speed models. Bonneson [15] constructed a relationship between curve speed and influencing factors including approach speed, radius, and super-elevation. For that model development, vehicle speed data were collected on horizontal curves at 55 sites on urban low-speed and high-speed roadways, rural low-speed and high-speed roadways, and turning roadways.

Only a few operating speed models have been developed for urban tangent streets. The posted speed limits were identified as the only significant variable or the most significant predictor of operating speeds in models for straight sections [6,12,16]. In a study conducted by Wang et al. [10], the 85th percentile cruising speed model and the 95th percentile cruising speed model were developed for low-speed urban tangent streets using data collected by in-vehicle global positioning system (GPS) devices. The final speed models in that study developed without including the posted speed limits showed that roadside density, driveway density, availability of sidewalk, and presence of on-street parking were negatively associated with drivers' speeds, while the number of lanes, curb presence, and commercial and residential land uses were positively associated with operating speeds. Details on previous operating speed models for urban streets are provided in Appendix A.

Several observations and conclusions can be drawn from the reviewed models and studies. First, existing operating speed models, including models for urban tangent sections, were calibrated based on only data for streets with speed limits of 40 km/h or more. Those models are therefore not applicable for residential streets with a 30 km/h speed limit. Second, most studies used spot-speed data for model development. Researchers developing tangent models usually assume that the highest speeds occur at the midpoint of a tangent section. However, with profile-speed data recorded by GPS devices, Wang et al. [10] found that the midpoint speed assumption is not realistic and drivers can reach their maximum speeds at different locations along a tangent. To date, the study by Wang et al. [10] is the only one that modelled operating speeds on urban streets based on continuous speed data. However, those data were not limited to free-flow speeds because information related to the time headway between vehicles was not collected by the GPS devices. Another issue with previous studies is that, available speed models used data for streets with different speed limits. While the speed limits were found to be a significant independent variable in most existing speed models, street geometry and other roadway and roadside characteristics were also highly correlated with speed limits [10]. Because of this high correlation, it may be difficult for research design and modelling efforts to separate the effects of speed limits from other street characteristics. If a study is to reveal the influence of street characteristics outside of speed limits on drivers' speed choice, it would be better to develop speed models based on single speed-limits. In addition, prior studies focused only on tangent street sections that were long enough for drivers to get to a relatively constant speed. For local urban streets, especially for streets with a 30 km/h speed limit, the length of tangent sections between two restricted points such as intersections is usually rather short; therefore drivers may not have enough time to maintain constantly their desired driving speed. From this point, differences in speed choice behaviours between residential streets with a 30 km/h speed limit and other types of streets are expected.

Previous studies used single-equation regression for modelling operating speeds on urban tangent street sections. If data were available for modelling multiple locations along a street, separate models were developed for each point. The underlying assumption of the single-equation regression approach is that there is no endogenous relationship between dependent variables. However, when the locations under study are close, as is the case of residential streets with a 30 km/h speed limit, it is necessary to test the potential endogenous relationship between speeds at the two locations. For this modelling effort, an effective way is using a simultaneous equation approach with a three-stage least square (3SLS) estimator. This approach has been used in several speed-related studies [17–20]. For example, Shankar and Mannering [17] and Himes and Donnell [20] showed that the approach is a powerful tool for discovering endogenous relationships between mean-speeds and speed deviations in different lanes on multilane highways.

In-vehicle GPS devices are effective in collecting continuous speed data as illustrated by Wang et al. [10] and Zuriaga et al. [21]. One shortcoming of the GPS methodology is that it is not completely limited to free-flow speeds because no information related to the time headway between vehicles is recorded. In addition, driver speed behaviours may be affected after installing GPS devices on their vehicle. Meanwhile, speed radar guns have been used to collect speed data for many speed-related studies, and some models of speed radar guns such as STALKER ATS can be used for recording continuous speed data. Although, the appearance of speed surveyors in the field may influence drivers' speed choice and some potential bias from the cosine effect and interference error may exist, reliable data can be obtained if appropriate considerations are taken during the survey.

3. Research objectives

The objective of the current research is to develop models for predicting operating speeds on tangent sections of urban residential streets with a 30 km/h speed limit. The influences of various roadway and roadside elements on drivers' speed choice in terms of maximum speed and speed at the entrance to the next un-signalised intersection were evaluated in this study. Continuous speed data were used instead of spot-speed data. In addition, the appropriate modelling approach for short-length tangent sections is described in this paper.