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Model of Quantitative Evaluation of Traffic Circulation Plan
Based on Traffic Conflicts

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Abstract

Traffic impact studies (TIS) have been required by transportation agencies to evaluate the potential transportation impacts of the proposed development on the surrounding neighborhood since 2001 in Beijing. The analysis on the negative aspect brought by proposed projects in terms of improper location and excessive number of driveways or inappropriate opening of median becomes the focus of TIS. However, the analysis of the traffic conflicts generated by proposed development has been so far limited to qualitative interpretation and conflict diagrams in traffic impact reports, which makes it difficult for traffic professionals to evaluate traffic circulation plans. The objective of this paper attempts to explore to quantify traffic conflicts analysis. Concept of conflict complexity is, for the first time, introduced in this study as a new evaluation indicator. The model to estimate conflict complexity is then built up by putting vehicle-bicycle conflict, vehicle-pedestrian conflict and vehicle-vehicle conflict into consideration. This indicator can be used to quantitatively determine if traffic circulation proposed in TIS report is justified. Finally, based on the data from 65 TIS reports from Beijing city the threshold values for criterion are determined in the study. The result from this study will help transportation agencies make decision for the proposed projects in quantitative manner. In addition it can also pave the way for the standardization of traffic circulation procedure.

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1. Introduction

A lot of traffic impact studies (TIS) of development projects have been carried out since 2001 in Beijing based on the requirement of planning regulations issued by Beijing Urban Planning Committee in 2000. TIS has played a positive role in coordinating the relationship between urban development and transportation infrastructure construction as well as in relieving severe unbalance between traffic supply and demand. In general, there are three elements involved in TIS in Beijing. They include change of v/c ratio at intersections, quality of public transit service, and traffic circulation. The first two elements have been studied for many years in Beijing and the corresponding evaluation indicators are given in quantitative format as indicated in the study [(The Transportation Planners Council of The Institute of Transportation Engineers, 1988), (Donald L. Wolfe, 1997), (BJUT, 2008)]. However, the analysis of traffic circulation has always been discussed in qualitative way in TIS, leaving arbitrariness in conclusion. The very reason for this is that there is a lack of criterion to dictate analytical process of traffic circulation. Therefore, this paper attempts to develop a new evaluation indicator named “conflict complexity” as a criterion to determine if the traffic circulation at proposed development area meets the requirement of traffic conflict perspective.

The traffic circulation is defined in this study as ways of controlling and managing on accesses of proposed development and connections to the adjacent roadways. Three types of traffic conflicts at proposed development area can be categorized based on the interactions between traffic flows. The first type of conflict in this study refers to the conflict between motor vehicle and non motorized vehicles (such as bicycle and e-bike). This type of conflict is vital in the evaluation of TIS because the conflict will result in serious injury or casualty based on statistical data bank. The second type of conflict denotes the conflict between motor vehicle and pedestrians in light of the fact that high percentage of people makes their trips by walk. Like the first type of conflict this conflict is also considered an important factor in projects of the evaluation of traffic impacts (TIS). The third type of conflict deals with conflicts among motor vehicles. This kind of conflict is often talked about in safety studies. As is known this kind of conflict diminishes at signalized intersections because signal indications assign right-of-way for traffic movements from different directions, resulting in the decrease of possible conflicts between vehicular traffic.

In the process of evaluating a project these three conflicts are often discussed in qualitative way without giving specific answer to the question if the traffic circulation plan is acceptable or not. To overcome this deficiency a mathematical function reflecting the degree of conflicts from three aspects: vehicle versus bicycle; vehicle versus pedestrian, and vehicle versus vehicle is built up to quantitatively evaluate the traffic circulation plans. The given model is the product of these three conflicts with consideration of other constrains. The higher the value of the conflict complexity, the severer the conflicts are, demonstrating that traffic circulation plan is bad.

For any TIS there are three classes for evaluation conclusion in accord with specification of documents issued by Steering Committee of Beijing Urban Planning Committee. They are: acceptable; rejected and needing modification. The class of needing modification means the project itself to be modified but not to be reconstructed. Each class falls in corresponding values produced from the model. The threshold values are determined based on the results from the studies of 65 TIS reports in Beijing.

It should be mentioned that there are very few studies related to modeling of traffic conflicts in TIS from literature review. This is the first exploration in this area.

2. Literature review

With the rapid development of urban areas, more and more complex conflicts from highway traffic are
greatly affecting performance of urban transportation network. There are many studies of traffic impact in China and abroad, focusing on conflicts between vehicular traffic and bicycle as well as pedestrians. Traffic conflict is one of the main traffic safety problems that researchers are trying to understand and resolve.

There are many studies of traffic conflicts on urban roads. For example, the influence of driving behavior on traffic conflicts, the relationship of traffic flow complexity and traffic conflict, vehicle-bicycle conflicts are topics discussed by traffic professionals and elected officials. Several papers that used traffic conflicts at signalized and unsignalized intersections as a tool for evaluating the relationship between the accidents and conflicts are also described.

A study by Parker and Zeeger in 1989 was performed to produce guidelines for collecting conflict data in the United States. This report produced a guide for engineers, which addresses issues such as sample size, conflict types, conflict definitions, and conflict analysis (Mohammed T. Mallah, 2003). The paper written by Xing Ge, Jian Lu presented a model indicating the relationship between driving behavior and conflicts at unsignalized intersection based on the impact on traffic operating and safety (Xing Ge and Jian Lu, 2008). The paper studied the driving and riding behaviors during intrusion conflicts in vehicles-bicycles mixed flow, indicating that some bicyclists would intrude the lanes reserved for vehicles from time to time. A cellular automata model is proposed to model such conflicts and examine the variation process of traffic flow rate according to the density of vehicles and bicycles (Sihan Cheng and Yuelong Su, 2008).

Zhang and Wang (Zhang Xiao Lin and Wang Wei Dong, 2005) proposed ranking evaluation approach using 1 to 5 in their project study. In their study distance from access to the nearby intersection and number of entrance/exit of parking garages from developments became the main evaluation index in their regression model. Yang and Cao (Yang Xiao Kuan and Cao Jing, 2008) also built a model of traffic circulation reflecting number of driveways connecting to roadways. They used density (number of driveways for each kilometer) to assess the conflict complexity due to excessive direct connections to main street.

3. Objective of the study

The objective of this study is to put forward a comprehensive indicator to evaluate traffic circulation at proposed development site to determine if the project is accepted, or needed to modify, or rejected from perspective of traffic conflict intensity. To this end conflict complexity has been introduced in this study and its mathematical equation is built in order to quantify the conflicts brought about by the proposed development. The utmost motivation behind conducting this kind of research is to simplify the process of TIS evaluation in traffic conflicts and avoid uncertainty in discussing traffic circulation.

4. Methodology

It’s critical for transportation agencies reviewing TIS to evaluate the interference of the traffic generated from a proposed development with the traffic of the existing roadways or arterials. This interference is one of major elements in TIS. Proper location of accesses of proposed development can make existing road network operate well, eliminating the traffic congestion and potential danger. A concept of “conflict complexity” is proposed in this study as a quantitative indicator of the evaluation of traffic circulation in the study. Conflict complexity represents intensity and the levels of conflicts among any traffic movements within the nearest intersection caused by the proposed projects. This indicator is used to evaluate levels of traffic circulation plan on the basis on types of conflicts within affected area. Its mathematical equation can be expressed as follows:
\[
C = \sum_{i=1}^{m} K (1 + \lambda_{B} \delta_{B}) (1 + \lambda_{P} \delta_{P}) \sum_{i=1}^{n} \frac{N_{i} + N_{j}}{2} C_{n} \\
\]  

where,

\( C \) — conflict complexity;  
\( m \) — the number of accesses connected to the roadways  
\( K \) — distance punishment factor, and its values are shown in Table 1;  
\( C_{n} \) — conflict intensity corresponding to nth conflict (n=1,2,…9), the value is shown in Fig. 2;  
\( \lambda_{B} \) — vehicle-bicycle conflict factor;  
\( \lambda_{P} \) — vehicle-pedestrian conflict factor;  
\( \delta_{B} \) — conditional variables;  
\( \delta_{P} \) — conditional variables;  
\( N_{i} \) — the number of lane of conflicting flow i;  
\( N_{j} \) — the number of lane of conflicting flow j.

5. Discussion of parameters

5.1. Distance punishment factor \( K \)

The value of \( K \), defined as punishment factor, reflects how long the distance from access (driveway) connected to the proposed development to an intersection is, representing the impact of access on the performance of the intersection. The longer the distance is, the less the impact is, and vice versa. The values of Table 1 are based on the findings from Beijing. There have been some studies in Beijing on the design and layout of driveways close to a nearest intersection. The studies show that when distance \( K \) is 50m or shorter there is a great impact on the traffic of the intersections. Besides, crashes at access point are often seen due to the visibility problem and unexpected maneuver of drivers from driveways. Likewise, when this distance is 150m or longer this impact diminishes and can be neglected as indicated in the study (BMICPD,2004). It should be noted that functional area and corner clearance defined in Access Management Manual have not been so far addressed in the design criterion of intersections in China. Therefore, there is no standard to follow in identifying where access can best be located. Therefore, the values in Table 1 are site specific and can be used only for the developments of Beijing.

The distance from access D is measured from the central line of the driveway (access) to the curb of near sidewalk as shown in Fig. 1.

<table>
<thead>
<tr>
<th>Distance from Access D (m)</th>
<th>( \geq 150 )</th>
<th>50-150</th>
<th>( \leq 50 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K )</td>
<td>1</td>
<td>1.25</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 1. Punishment factor
5.2. Vehicle-bicycle conflict factor

As is known bicycle travel possesses high percentage of the total trips in urban area. This is particularly true in small and middle sized cities in China, where car ownership is relatively low. Even in major cities like Beijing there are a lot of bicycle riders. The latest (2010) OD survey for commuter travel conducted by Beijing Municipal Commission of Transportation showed that there were 28.5% of commuters in Beijing who travel by bicycle or e-bike, indicating that bicycle is still an important transportation means in intra-city travel in Beijing. It is important to put vehicle bicycle conflict into consideration when conducting traffic circulation work.

If traffic circulation is designed such that bicycle and vehicular traffic are running in separated way, it is considered that there is no conflict between bicycle and motor vehicle. At this moment the conditional factor $\delta_B$ is zero. However, in most cases bicycle and automobile can‘t be operated into fully segregated way due to the constraints of land use and right-of-way issues. It is very difficult to estimate exact impact of bicycle-vehicle conflict on traffic circulation with regard to different location or land use feature. Surveys have been conducted to investigate such impact. The results from survey show that majority of people think that conflicts between bicycle and vehicle at residential, commercial and office areas are crucial. Statistically, this group of people possesses 71% of all surveyed. Therefore, the vehicle-bicycle conflict factor $\lambda_B$ is 0.5 for residential, commercial and office building area; whereas 0.2 for other area.

5.3. Vehicle-pedestrian conflict factor

This factor is also important in the traffic circulation plan because vehicle-pedestrian conflict often results in the serious injury or casualty, which will greatly degrade the image of local government. Facing pressures from the public all levels of government in China do everything possible to exercise traffic calming strategies to keep community in a peaceful and calming environment. To reach this goal human-centered development and land use strategies have been initiated in the urban planning. From transportation perspective it is required that the community should be planned and constructed to be pedestrian oriented.

In this model vehicle-pedestrian conflict factor $\lambda_P$ has been introduced in order to reflect the levels of traffic circulation. In general if facilities for pedestrians have been adequately provided in the development such as provision of overpass or underpass for pedestrians to cross street or installation of signal for pedestrians to cross, it is considered to separate pedestrian flow from vehicular traffic.
thoroughly. Under this circumstance the conditional variable for vehicle-pedestrian conflict $\delta_p$ is zero. Based on the study (Beijing transportation Research Center, 2006) conflicts between pedestrians and motor vehicles are more vital in residential and commercial areas than in other areas. Results from this study show that residents and shoppers are more sensitive to the provision of pedestrian’s facilities and prone to live in the community and do shopping if their activities are free from vehicular traffic. Therefore, the value of vehicle-pedestrian conflict factor $\lambda_p$ is 0.5 for residential and commercial area, whereas 0.2 for other area.

6. Conflicts intensity

From the Equation 1, it can be found that the most critical thing is to identify the conflict intensity of various traffic conflicts that drivers have to experience caused by the traffic circulation plans.

6.1. Classification of traffic conflicts

At present, there are various methods to classify the traffic conflicts (X.M. Liu and H.L. Duan, 1997). Based on the possible collision of any two traffic flows from different directions conflicts can be classified into 9 classes in this study as shown in Fig. 2.

![Fig. 2. Classification of traffic conflicts](image)

6.2. Quantitative identification of each class of conflicts

In order to determine the relative value of each type of conflicts shown in Fig. 1 surveys had been conducted among drivers, traffic professionals, and traffic management. The value for conflict class 1 (diverge) is assumed to be 1 because it is believed to be the slighted conflict among all conflicts. The greater the value of $C_n$ is, the higher the conflict intensity is. The values of different conflicts are shown in Fig. 3. The determination of values is through review of reports of traffic accidents in Beijing. There is an evaluation formula from the severity of traffic accidents conducted by Beijing Traffic Management Bureau. The severity is divided into five categories per injury/fatality as well as economic losses caused by a specific type of accident. From the data bank it is found that merge related crash has the lowest rating; whereas head on crash has the highest rating. The right angle crash ranks the second in severity and the economic losses of right angle crash are about 8 times of merge related crash. In addition left turn crash data are also analyzed and the economic losses of left turn crash are 4.8 times of merge related
crash. It should be mentioned that the economic losses included compensation due to the injury such as medical treatment fees. However, the data of fatality are not considered in the analysis because there is no correlation between fatality and crash type (the data are too scattered distributed).

6.3. Criterion of evaluation of traffic circulation

Once conflict complexity is estimated based on Equation 1 a question will be raised as how to evaluate the value of the conflict complexity. As introduced at the beginning of this paper there are three classes for evaluation conclusion for traffic circulation of a proposed development. To obtain the threshold value of each class, 65 TIS reports of Beijing are reviewed and the results are shown in Table 2 and Fig. 4, respectively.

Basing on the results of Fig. 4, it is found that the values of conflict complexity are 90 at 15 percentile and 120 at 85 percentile, respectively. Therefore, the threshold value of conflict complexity is given as shown in Table 3.
Table 2. The evaluation conclusion of various proposed projects

<table>
<thead>
<tr>
<th>Evaluation Conclusion</th>
<th>Category</th>
<th>Number</th>
<th>Average value of conflict complexity C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accepted</td>
<td>Residential</td>
<td>6</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Official</td>
<td>8</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>4</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>2</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>8</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>Official</td>
<td>7</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>10</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>5</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>3</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Official</td>
<td>5</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>6</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>1</td>
<td>133</td>
</tr>
<tr>
<td>Rejected</td>
<td>Residential</td>
<td>3</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Official</td>
<td>5</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>6</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>1</td>
<td>133</td>
</tr>
</tbody>
</table>

Table 3. Criterion for Evaluation Conclusion of Traffic Circulation

<table>
<thead>
<tr>
<th>Evaluation Conclusion</th>
<th>Accepted</th>
<th>Needing Improvement</th>
<th>Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of C</td>
<td>≤90</td>
<td>90–120</td>
<td>&gt;120</td>
</tr>
</tbody>
</table>

7. Evaluation and analysis of a case study

A case study is conducted to demonstrate the process of model calculation. The case is a development of Business Building, which is located on the northwest corner of Jianguomen bridge in Xicheng District of Beijing.

There are two accesses connecting to the adjacent roadway within the study area. The north access is controlled by traffic signal with pedestrian overpass, therefore, there is no need to evaluate the “conflict complexity” for this access. The south access forms a "T" intersection with the direct connection to an urban road as shown in Fig. 5.

![Fig.5. Traffic circulation of south access](image)

The distance from the south access to the nearest intersection is 40m. Since it is less than 50m, the
value of K for this case is 1.5. At the same time the number of pedestrians and bicycle riders is very few at the south access. The conflicts of vehicle-bicycle and vehicle-pedestrian can be neglected at this situation. Thus, the value of λ_B and λ_P is 0. Then the value of conflict complexity can be calculated.

\[
C = \sum_{1}^{m} \left[ K(1 + \lambda_B \delta_B)(1 + \lambda_P \delta_P) \sum_{1}^{n} \frac{N_i + N_j}{2} C_i \right] \\
= 1.5 \times 1.41 \times 24 = 50.8
\]

As compared to the value shown in Table 3, it is seen that the traffic circulation plan is acceptable from traffic circulation perspective.

8. Conclusion and further study

The evaluation indicator of conflict complexity is proposed in this study to reflect the collision levels of traffic circulation of proposed development. The purpose of proposing this indicator is to quantify the evaluation process of traffic circulation, avoiding arbitrariness in the evaluation of traffic circulation plan. With this indicator transportation agencies can easily figure out if the traffic circulation plan is agreeable with the criterion as indicated in Table 3 and determine if the proposed development is acceptable from traffic circulation perspective.

It should be noted that this study is preliminary and leaves much to be improved. There are some limitations of the proposed methodology. For example, new developments often are featured with mixed land-use, resulting in difficulty in clarifying if the study area is taken as residential, office, or commercial. It should be noted that some default values in this study are kind of arbitrariness. Apart from that the values of conflict intensity shown in Fig. 3 are needed to discuss in the future study.

References


