**Capacity and Delays at Intersections Without Traffic Signals**

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**ABSTRACT**

Two-Way-Stop-Control (TWSC) is a form of intersection operation with widespread use. Usually, the calculations for the Level of Service are based on gap acceptance theory. In the American HCM, the influence of pedestrians is considered by an impedance factor, whereas in the German guideline the influence of pedestrians and bicyclists is not considered so far. To close this gap an alternative calculation method, called conflict technique has been developed. This method allows to consider the influence of non-motorized road users on the traffic performance for motor vehicles. Moreover, the method provides a significant simplification of the whole theoretical approach. Different modalities of operation like a zebra crossing on the entries to the intersection can be considered as well as the fact that some road users do not comply with the priority rules. It is possible to calculate the capacity for one minor movement out of one single equation. To calibrate the calculation method, traffic on several intersections was observed by video and analyzed by traffic volumes, delays, compliance to priority rules and other parameters. With these field measurements the calculation method was calibrated to real road user behavior. The comparison of the conventional calculation concept based on the gap acceptance and the new conflict technique showed similar results. Especially the implication of pedestrians and of limited priority effects turns out to be a considerable benefit of the new method.
INTRODUCTION

Unsignalized intersections with two-way stop control (TWSC) establish a type of intersection which is most frequently used for traffic control both in urban and rural environments. In practice their capacity is mainly calculated to compare the performance for this type of operation with intersections controlled by traffic signals, roundabouts, or grade separated intersections. To estimate the Level of Service for TWSC intersections the gap acceptance method according to HARDERS, SIEGLOCH, GROSSMANN (1,2,3) plus many other authors is used in many countries of the world (e.g. USA (HCM)(4), Germany (HBS) (5)). In Germany this calculation method was calibrated based on observations at rural intersections without any pedestrians or significant bicycle traffic.

To evaluate the Level of Service of urban intersections it is inevitable to consider also the non-motorized road users. On the one hand these road users influence the motorized traffic. On the other hand pedestrians and bicyclists suffer delays caused by the motorized traffic.

Therefore a research project sponsored by the German Federal DOT (6) was carried out by the authors. As a result, a new procedure for estimating the capacity of TWSC-intersections was developed.

TRAFFIC MOVEMENTS AND PRIORITY

To consider pedestrians and bicyclists in addition to the motorized road users, their movements have to be defined together with their ranking of priority. As usual, 12 vehicle movements can be identified at an intersection (fig. 1). In addition, 8 pedestrian movements (one per entry and per exit) plus 4 movements of bicyclists on separate bicycle paths (SBP) have been defined. Bicyclists using the roadway are treated together with the vehicle movements.

To describe the model a precise description of the priority rules should be given. Of course, the through traffic on the major street has an absolute right of way, which has to be observed by pedestrians crossing the major street. All turning movements have to observe the priority for all the movements which walk or drive in the direction parallel to the original direction. Thus, pedestrians have priority over turning movements on all intersection exits.

So according to the German highway code:

- turning vehicles leaving the intersection have to give way to pedestrians,
- vehicles entering the intersection have the right of way over pedestrians,
- through traffic always has the right of way over pedestrians.
- Pedestrians on zebra crossings have the priority over all vehicle movements.
- Bicyclists driving on a SBP have the right of way over turning vehicles. If the bicycle path is parallel to the major road, the bicyclists have priority over every other road user.

These complex rules cannot be modeled correctly by gap acceptance theory, which requires a fixed ranking of all movements by priority as well as a tight compliance with the priority rules. Since such a strict ranking of priorities is not established by the highway code and since the rules are not completely obeyed by road users in reality, the gap acceptance method is not suitable for considering pedestrians and bicyclists in addition to the vehicle traffic. Within the research project (6) it was attempted to extend the gap acceptance method by considering pedestrians and bicyclists under a compliance with the priority rules. However the calculation method is not able to model traffic rules consistently and, moreover, it is hardly applicable in practice.

So it seemed to be necessary to develop a completely different approach. This alternative method is based on the ideas of WU (7). He developed a procedure for all-way-stop-controlled intersections. Based on these ideas, BRILON, WU (8) drafted a corresponding method for TWSC intersections. These ideas combined with an empirical survey resulted in a new method, which is ready for use in practice. Pedestrians, even on zebra crossings, can be considered as easy as bicyclists on their SBP. It is possible to consider either the full compliance with the priority rules or the actual acceptance of priority rules by road users.

CONFLICT MATRIX

According to fig. 1, a road user is assigned to one of the 24 movements. To express which traffic movement has the right of way over another one, MILTNER (9) proposed a so-called conflict matrix. This matrix (fig. 2) represents
all the existing priority rules as they are valid in Germany and in a very similar manner in the other continental European countries.

If one movement interferes with another one, the cell of the matrix contains a value \( A_{ij} \). If \( A_{ij} = 1 \), then movement \( i \) (conflicting movement) has priority over movement \( j \) (subject movement). If \( A_{ij} = 0 \), then \( i \) has to give way to \( j \). For example in fig. 2 movements 2 and 4 are marked:

- \( A_{24} = 1 \): conflicting movement 2 has the right of way over subject movement 4
- \( A_{42} = 0 \): conflicting movement 4 has to give priority to subject movement 2

The \( A_{ij} \)-values for pedestrians and bicyclists can be understood in analogy.

**CONFICT TECHNIQUE**

The new type of model does not claim to be exact mathematics. It simplifies the operation of the intersection by a plausible analogy to queuing systems. The easiest way to understand the basic idea of this calculation method is to consider the 2-stream-problem: An intersection of two one-way streets (fig. 3). To pass the intersection, the road users from both traffic movements have to use the conflict area. Road users from the minor movement can only pass the intersection if no major vehicle is using the conflict area.

Knowing the duration, that a major street vehicle (conflicting movement) is blocking the conflict area and the volume of the major traffic stream, the probability that the conflict area is blocked by a conflicting road user is estimated as

\[
 p_s(x) = \frac{1}{3600} \cdot q_1 \cdot t_{s,i} 
\]

\( p_s(x) \) probability that the conflict area is occupied by a vehicle of movement \( i \)  
\( q_1 \) traffic volume of movement \( i \)  
\( t_{s,i} \) occupation time caused by one major stream vehicle \( i \)

Thus, \( 1 - p_s(x) \) is the probability that the conflict area is not occupied by a vehicle of movement \( i \).

For a waiting minor vehicle the conflict area is also blocked, if a major vehicle is approaching the conflict area. A waiting driver only enters the intersection, if he can pass the conflict area before the next major vehicle arrives. To express this effect, we define a time margin \( t_{s,i} \) (in advance of major vehicle \( i \)'s arrival) during which no minor vehicle would be able to enter the conflict area. This time has some similarities with the critical gap. Then the probability that the conflict area is not blocked by an approaching vehicle is estimated by eq. 2, assuming that the major stream gaps are exponential distributed.

\[
 p_{0,a}(x) = e^{-\frac{1}{3600} \cdot q_1 \cdot t_{a,i}} 
\]

\( p_{0,a}(x) \) probability that the conflict area is blocked by an approaching vehicle from movement \( i \)  
\( q_1 \) traffic volume of major movement \( i \)  
\( t_{a,i} \) time margin during which an approaching major vehicle \( i \) is blocking the conflict area in advance of its arrival

A minor street vehicle can only enter the conflict area if both conditions are fulfilled simultaneously:

- the conflict area is not used by a major vehicle,
- no major vehicle is approaching the intersection.

The probability that both conditions are fulfilled, is

\[
 p_0 = (1 - p_s(x)) \cdot p_{0,a}(x) 
\]

We define the maximum throughput for minor movement \( j \) as that number of vehicles per time unit, which could pass the intersection if no major vehicle would arrive at any time (i.e. \( q_i = 0 \)), as \( q_{\text{max},j} = 3600/t_{s,i} \), where \( t_{s,i} \) is the occupation time (cf. eq. 1) for a minor vehicle of movement \( j \).
Then the actual capacity for movement \( j \) can be expressed as

\[
C_j = C_{\text{max}, j} \cdot p_0
\]

\( C_j \) capacity for minor movement \( j \) [veh/h]
\( C_{\text{max}, j} \) capacity for minor movement \( j \) without influence of another traffic movement (= 3600 / \( t_{s,i} \)) [veh/h]
\( p_0 \) probability that the conflict area is not blocked (eq. 3) [-]

In comparison to the 2-stream-problem, the calculation of capacities for real intersections is more complex. To consider all 24 movements, more than one conflict area has to be examined for each minor movement. All these conflict areas can be arranged into 12 groups of conflicts (we denote one such an arrangement of conflicts as “conflict group”) as they have first been proposed by Wu (7) (fig. 4). One conflict group contains those conflict points that are situated closely together within the intersection such that they can only be occupied by one vehicle at any time. Table 1 shows, which traffic movements \( i \) belong to the different conflict groups \( k \). Each road user has to pass several of these conflict groups to get through the intersection. Therefore, the road user can only enter the intersection if all conflict groups, which he has to pass, are free of other road users. Thus, the probability \( p_0 \) that all conflict groups are free of traffic determines that portion of time during which the intersection is accessible for the minor movement under concern. With that the capacity for each movement \( j \) at a real intersection is:

\[
C_j = C_{\text{max}, j} \cdot p_0
\]

\( C_j \) capacity for traffic movement \( j \) [veh/h]
\( k \) index for a conflict group [-]
\( i \) index for a traffic movement [-]
\( D_k \) number of movements within conflict group \( k \) [-]
\( q_{i} \) traffic volume of movement \( i \) [veh/h]
\( t_{s,i} \) occupation time caused by a vehicle from movement \( i \) [s]
\( t_{a,i} \) time margin during which an approaching major stream vehicle \( i \) is blocking the conflict area in advance of its arrival [s]
\( A_{i,j} \) conflict factor to consider the priority rules [-]

For each movement (1 through 12) it is possible to calculate its capacity in one step according to eq. 5. No stepwise calculations with impedance factors for different rankings of priority are required, like it is the case in gap acceptance theory. Here the ranking is replaced by the \( A_{i,j} \)-factor, which represents the priority rules. These factors for the German highway code can be obtained from the conflict matrix given in fig. 2. Eq. 5 can be universally applied for all vehicle movements, even for the major streams, which might be influenced e.g. by pedestrians on a zebra crossing.

Once the capacities have been calculated, shared lanes and short lanes can be considered and average delays can be calculated according to the corresponding equations as they are given in the American HCM (4) or the German HBS (5). Thus, the further derivations for the Level of Service are completely according to the conventional procedures (e.g. eq. 17-55 of the HCM (4)).

**DIFFERENT RULES OF OPERATION**

The calculation method according to the conflict technique (eq. 5) implies also the potential for a consideration of alternative priority rules at the intersection. For instance, one entry of the intersection might be equipped with a zebra crossing which provides the absolute right of way for pedestrians crossing the street at this point. As an example fig. 5 shows a conflict matrix for the case of a pedestrian crossing on the western entry. We see that all the \( A_{i,j} \) values for \( i = F1 \) and \( i = F2 \) (both relevant pedestrian movements which are using the zebra crossing) are given as 1, indicating their absolute priority over vehicle movements, whereas the values for \( j = F1 \) and \( j = F2 \) are
zero. Using this conflict matrix for the $A_{ij}$ in eq. 5 we get the capacities for all movements in case of a zebra crossing on the western approach of the intersection.

It is also possible to use the same calculation method according to eq. 5 for both, four-legged intersections and T-junctions. Movements not existing at T-junctions are not considered, since their traffic volume is $q_i = 0$. Also the case where the turning movements between two arms of the intersection get priority (a solution which is used in European countries) can be expressed by a specific conflict matrix and can then be solved by eq. 5 without any change of the basic procedure.

**ACTUAL COMPLIANCE WITH PRIORITY RULES**

Traffic operation at 13 urban intersections has been observed (6) by video taping over a period of several hours at each site. The intersections selected for these experiments had relatively severe traffic of all kinds of road users. One aspect of the survey was to calibrate the model and to compare observed and calculated capacities. The more important aspect, however, was to determine the behavior of the road users according to priority rules. The videos taken showed very clearly many cases of priority reversal. These were behaviors either of gap forcing or of politeness, where one driver stopped to let another road user go ahead. E.g. if a driver from a priority movement notices a long queue in the minor street he might be inclined to stop allowing the queued vehicles to find their way through the intersection without further delay. This kind of priority reversal happens since it might not cause a long delay for the major driver but it helps the minor vehicles a lot. On the other hand, some vehicles or even pedestrians rush into the conflict area to force a priority vehicle to stop. All these kinds of behavior have been observed and all kinds of road users can be on both sides, the “winners” of the conflict or the delayed conflict partners. It turned out that each specific type of conflict showed a typical picture.

Fig. 6 indicates the results in more detail. We see compliance with traffic rules among vehicle movements between 82 and 96 %. Fig. 7 illustrates the conflict solution between motorized vehicles and pedestrians. Here we see that especially turning vehicles violate the priority of pedestrians in the majority of conflicts. Left turning vehicles force their way against the pedestrians at the exit of the intersection in around 60 % on average. On the other hand there are also cases (around 50 %) where the vehicle drivers from the minor street give way to pedestrians even if the rules define a priority for vehicles. One of the reasons for this significant differences between traffic rules and road users’ behavior could be the fact that both kinds of partners have only a bad knowledge about the official rules. This was evaluated by formalized interviews (6).

The observations of traffic rule compliance have also been expressed in a matrix as it has been introduced in fig. 2. Now this modified conflict matrix expresses, to which degree $A_{ij}$ the conflicting movements $i$ have priority over the subject movements $j$. These $A_{ij}$-values are rounded averages over all 13 observed intersections. To understand the degree of priority reversal these figures should be compared to fig. 2, which expresses the highway code. Then we see the rather unexpected large deviations from the official traffic rules as they have already been shown in fig. 6 and 7. E.g. in 60 % of all conflicts the major street left turner (movement 1 or 7) does not obey the priority of the pedestrian (F7 or F3 respectively). In 10 % of the conflicts also pedestrians forced vehicles to let them go ahead. The figures tell us that there is nearly no absolute priority in real life practice at unsignalized intersections. Instead we see that all the priorities are limited.

On this background it is questionable if it is useful to apply calculation methods which assume a full compliance with the highway code, since – of course – the limited priority behavior has a significant impact on capacities and delays.

The results from the analysis of the average “degrees of priority” as it is expressed by the conflict matrix in fig. 8 can be introduced into eq. 5. All the $A_{ij}$-factors in fig. 8 which express realistic road user behavior can be used within this equation without any change of the model. Note: $A_{ij} = x$ means: in $x \times 100$ % of the conflicts between movements $i$ and $j$, movement $i$ goes ahead of $j$. More simple speaking: $A_{ij}$ is the degree of priority for $i$ over $j$. Of course it is required that $A_{ij} + A_{ji} = 1$.

**PARAMETER ESTIMATION**

For practical use of the model it is necessary to know the values of the parameters $t_a$ and $t_x$, which should have specific values for the different traffic movements. These values were calibrated based on the data from the 13 observed intersections mentioned above. In fact it is not possible to measure capacities directly as long as the intersection is not fully saturated. KYTE (10) proposed an approach to quantify the capacity of a vehicle stream based on two time parameters. The value $t_1$ represents the time, which a vehicle spends in the $1^{st}$ position of the queue. $t_{mv}$ is the required time for a vehicle to move up from the second into the first position of the queue. The sum of $(t_1 + t_{mv})$ can be regarded as the service time of the queuing system which is established by the
unsignalized intersection. The average of the sum \( t_1 + t_{mv} \) has to be evaluated over all observed vehicles out of each movement. In practice this measurement is only possible with limited precision. The reciprocal value of \( t_1 + t_{mv} \) is regarded as an estimation for the capacity of the movement under consideration.

\[
C = \frac{3600}{t_1 + t_{mv}}
\]

The capacities according to Kyte’s method (eq. 6) have been evaluated at 13 intersections for each of the vehicle movements. Observations have been made in 1-hour-intervals. On the whole, a set of 21 intervals was evaluated. For each interval all traffic volumes were also recorded. Using these volumes a routine was set up on a spreadsheet to calculate the capacities according to the conflict technique (eq. 5). Here the conflict matrix fig. 8 for the \( A_i \) was used, which represents the real average compliance with traffic rules. The differences between observed and calculated capacities were compared. By spreadsheet optimization technique (Excel Solver) the \( t_1 \) and \( t_{mv} \)-values in eq. 5 were modified such that the sum of the squared differences was minimized. The results are given in table 2. These values are proposed for practical use in Germany as the standard parameters of the conflict technique (eq. 5).

**HOW REALISTIC ARE THE RESULTS OF THE CONFLICT TECHNIQUE ?

The objective of calculation methods in transportation engineering is to model reality as close as possible. To check whether the conflict technique leads to realistic results, the calculated capacities were compared with the capacities observed at the intersections by Kyte’s method (fig. 9). Each point represents one minor movement during an interval of 1 hour. On the left hand side the calculations are based on the conflict matrix fig. 2, which represents the official traffic rules. The right part of the figure uses the conflict matrix in fig. 8 with the more realistic behavior patterns. The points are distinguished by movements. We see, on average, a good correspondence between estimations based on measurements (Kyte) and calculated capacities. For lower capacities the calculated results show a tendency to an underestimation. The residual variance is significantly lower using the realistic limited priority behavior (as it is expressed by fig. 8). This effect clearly indicates that the kinds and degrees of violation of priority rules should be considered to derive realistic capacities at unsignalized intersections.

Of course, this comparison has two kinds of problematic aspects:

- the parameter calibration and the verification use the same set of observations. This could not be avoided due to a limited amount of empirical data available and due to the tremendous costs for getting additional data. Due to the fact that the patterns of road user behavior vary considerably, quite a large number of observations would be necessary to get results of more general validity.

- Both compared estimates of capacity imply their own kind of uncertainty, since the Kyte-method does not deliver precise values.

To assess the quality of the conflict technique method, also a comparison with the conventional gap acceptance method was performed. However, the possibilities for comparison are limited. The gap acceptance method does not allow to consider pedestrians and bicyclists on SBPs. Thus, the comparison is limited to vehicle movements. For the test, 500 cases of traffic demand patterns at an unsignalized intersection were randomly generated. The volumes ranged as follows:

- 0 through 200 veh/h (movements 1, 3, 4, 6, 7, 12)
- 0 through 300 veh/h (movements 5, 9, 10, 11)
- 0 through 500 veh/h (movements 2, 8)

The gap acceptance method was applied using the critical gaps and follow-up times for urban intersections according to HBS (5). The parameters of the conflict technique were taken from table 2 (t-values) and fig. 2 (conflict matrix with complete compliance to traffic rules). Fig. 10 illustrates the results of the comparison. In most cases the capacities calculated by the conflict technique are slightly larger than the gap acceptance results, especially for the lower capacity movements (minor left turning vehicles, movements 4 and 10). For major street
left turners (1, 7), the capacity estimated by the conflict technique is lower than the gap acceptance results (C = 400 – 700 veh/h). Overall it is visible that both calculation methods lead to similar values. Existing differences can be explained by different parameters. We should note that the parameters used, result from completely different sources. On this background we can state that for vehicle movements under a perfect compliance with traffic rules (which is the unavoidable assumption for the gap acceptance method) both methods show a rather good correspondence.

CONCLUSIONS

The paper presents an innovative analysis method for TWSC intersections. In addition to vehicle traffic also pedestrians and bicyclists on separate bicycle tracks can be considered on a realistic background. This aspect of operation is important especially for urban intersections. The method is based on model assumptions which are a significant simplification of queuing model ideas. The derivations lead to a single equation for the calculation of capacity. This equation is applicable for all vehicle movements at the intersection. For use within this capacity equation the so-called conflict matrix was developed to represent the priority rules according to the highway code. This matrix makes it easy to consider all kinds of operation like zebra crossings and also the case where the turning movements get priority – a solution which is used on the European continent in several countries.

The conflict matrix can also express the acceptance of priority rules by drivers and pedestrians as it occurs in reality. A series of observations has been performed to get estimates for the degrees of compliance with the existing traffic rules. Especially for the conflicts between pedestrians and vehicle movements the real behavior disagrees considerably from the official rules. The research showed very clearly that a realistic estimation of capacities can only be achieved if the non-compliance with traffic rules is regarded within the calculation procedures.

Different comparisons showed that the new model leads to a realistic estimation of capacities, although more comprehensive data for calibration and verification are desirable. The comparison of the conflict technique with the gap acceptance method showed a reasonable agreement between both kinds of results.

The application of the method to the data sets from 13 urban intersections, which have also been used for calibration, showed – on average - a good coincidence of calculated values with observed capacities. However, the variation of results seems to be quite large. It was not possible to reduce this variance due to the wide range of different road user behaviors and due to the rather limited data. Therefore, the new method should be tested further. For Germany it is recommended to use it for a careful application in practice. Before it could be recommended as a standardized procedure more experience is required.

The new conflict technique has some significant advantages. The most important aspect is that it is the only method - known at present - which provides a reasonable concept to include pedestrians with their rather complex rules of priority ranking into the capacity calculation method. Due to this property the new methodology has the chance to become the first choice for urban TWSC-intersections. A second aspect is that limited priority and priority reversal can very easily be represented by this estimation technique. As a third aspect the fact has to be mentioned, that the whole procedure is contained in a single equation, which makes it very easy to implement the method into calculation procedures.

Finally it should again be emphasized that the new approach is concentrated on capacity estimation for all movements at an intersection. The procedures to derive performance parameters like delays or queue length and also shared lane effects remain the same as in the conventional methodology.

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TABLE CAPTIONS

TABLE 1 Allocation of Traffic Movements i to Conflict Groups k

TABLE 2 Parameters of the Model

FIGURE CAPTIONS

FIGURE 1 Definition of traffic movements at a TWSC intersection.

FIGURE 2 Conflict matrix

FIGURE 3 2-stream-problem.

FIGURE 4 Conflict groups at an intersection according to WU (7).

FIGURE 5 Conflict matrix applied to a pedestrian crossing for movements F1 and F2.

FIGURE 6 Percentage of priority rule acceptance between vehicle movements at a TWSC-intersection.

FIGURE 7 Observed sequence of pedestrians and vehicles in case of a conflict. Numbers indicate the proportion of cases. “w” denotes the wrong sequence compared to traffic rules.

FIGURE 8 Conflict matrix describing the average road user behavior at a TWSC-intersection.

FIGURE 9 Observed capacities (according to Kyte’s method) compared to capacities calculated by conflict technique for 13 TWSC-intersections.

FIGURE 10 Capacities calculated by conflict technique compared to capacities calculated by the German gap acceptance method.
### TABLE 1 Allocation of Traffic Movements $i$ into Conflict Groups $k$

<table>
<thead>
<tr>
<th>$k$</th>
<th>$i$</th>
<th>$k$</th>
<th>$i$</th>
<th>$k$</th>
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<td></td>
<td>veh</td>
<td>ped</td>
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<td>veh</td>
<td>ped</td>
</tr>
<tr>
<td>1</td>
<td>4, 8, 12</td>
<td>F1</td>
<td>R11</td>
<td>5</td>
<td>1, 4, 8, 11</td>
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<tr>
<td>2</td>
<td>3, 7, 11</td>
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<td>R2</td>
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<td>R5</td>
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<td>F7</td>
<td>R8</td>
<td>8</td>
<td>1, 5, 8, 10</td>
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</table>

(cf. fig. 4; e.g. vehicle movements 4, 8, 12, pedestrian movement F1 and bicycle movement R11 belong to conflict group 1)

### TABLE 2 Parameters of the Model

<table>
<thead>
<tr>
<th>Traffic Movement</th>
<th>$t_o [s]$</th>
<th>$t_a [s]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 7 (major Left Turn)</td>
<td>3,2</td>
<td>3,3</td>
</tr>
<tr>
<td>2 &amp; 8 (major Through)</td>
<td>1,8</td>
<td>2,0</td>
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<tr>
<td>3 &amp; 9 (major Right Turn)</td>
<td>2,0</td>
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<tr>
<td>4 &amp; 10 (minor Left Turn)</td>
<td>3,6</td>
<td>3,8</td>
</tr>
<tr>
<td>5 &amp; 11 (minor Through)</td>
<td>3,7</td>
<td>4,3</td>
</tr>
<tr>
<td>6 &amp; 12 (minor Right Turn)</td>
<td>4,1</td>
<td>4,8</td>
</tr>
<tr>
<td>Pedestrian movements</td>
<td>3,0</td>
<td>0</td>
</tr>
<tr>
<td>Bicycle movements</td>
<td>2,0</td>
<td>0</td>
</tr>
</tbody>
</table>

$t_o = \text{occupation time for one vehicle}$

$t_a = \text{time margin during which an approaching vehicle is blocking the conflict area in advance of its arrival}$
FIGURE 1  Definition of traffic movements at a TWSC intersection.
### Conflict Matrix

<table>
<thead>
<tr>
<th></th>
<th>subject traffic movement j</th>
<th>pedestrians</th>
<th>bicyclists</th>
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</thead>
<tbody>
<tr>
<td>i</td>
<td>1  2  3  4  5  6  7  8  9  10 12</td>
<td>F1 F2 F3 F4 F5 F6 F7 F8 R2 R5 R8 R11</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1  1  0  0  1  1  1  0  0  0  1  1  1</td>
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#### Definition for 1 and 0:

1: conflicting movement i has priority over subject movement j  
(e.g. vehicles of movement 2 have the right of way over movement 4)

0: conflicting traffic movement i has to wait for subject movement j  
(e.g. vehicles of movement 4 have to wait for vehicles of movement 2)

---

**FIGURE 2** Conflict matrix the German highway code representing.

**FIGURE 3** 2-stream-problem.
FIGURE 4  Conflict groups at an intersection according to WU (7).
**Conflict Matrix** (pedestrian crossing F1 F2)

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<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
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<th>R2</th>
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(marked boxes highlight the differences to conventional conflict matrix)

**Figure 5** Conflict matrix applied to a pedestrian crossing for movements F1 and F2.

**Figure 6** Percentage of priority rule acceptance between vehicle movements at a TWSC-intersection.

(movement numbers according to Fig. 1)
FIGURE 7  Observed sequence of pedestrians and vehicles in case of a conflict. Numbers indicate the proportion of cases. “w” denotes the wrong sequence compared to traffic rules.

FIGURE 8  Conflict matrix describing the average road user behavior at a TWSC-intersection.
- t-values according to table 2
- Conflict matrix according to fig. 2
- $s_{xy}^2 = 20,975 \text{ (veh/h)}^2$

- t-values according to table 2
- Conflict matrix according to fig. 8
- $s_{xy}^2 = 15,718 \text{ (veh/h)}^2$

**FIGURE 9**  Observed capacities (according to Kyte’s method) compared to capacities calculated by conflict technique for 13 TWSC-intersections.
FIGURE 10 Capacities calculated by conflict technique compared to capacities calculated by the German gap acceptance method.