Introducation

Hazardous situation, near miss, near accident and traffic conflict are all synonyms describing traffic situations with a potential accident risk. These situations show up as irregular events in the traffic stream without resulting in accidents. Most studies carried out on this subject have used different definitions to define the irregular events that represent a deficient situation from the safety and traffic operational point of view. This investigation suggests that a study of the regular flow of vehicles through an intersection should be included as part of the study of the irregularities, or the hazardous situations that may arise from them.

The various studies on this subject can be broadly divided into two groups:
1. Investigations that observe groups of drivers and vehicles under various traffic situations. These studies are mostly of a psychological-sociological nature, and include studies by Forbes (1957), Zuercher et al. (1971), McFarland & Moseley (1954), and others.

2. Investigations that observe a certain location or group of locations (generally an intersection or a bend). At such locations, the behaviour of drivers and vehicles is observed.

This category includes studies such as the "General Motors Traffic Conflicts Technique", first developed by Harris and Perkins (1959, 1969), studies by Campbell and King (1969), Baker (1972), Pught Halpin (1974), Paddock (1974), and others. Also included in this category are traffic conflict studies as developed by the TRRL, Spicer (1971, 1972, 1973), Amundsen (1974), studies by Guttingen and Kraay (1976) on conflicts in residential neighbourhoods, Hayward (1971, 1972), who was the first to introduce the concept of "Time to Collision (TMC)", and Hyden (1973, 1976), who further developed this concept.

Studies attempting to relate driving errors and violations, such as by Harvey, Jenkins and Summer (1975), also belong to this category.

Most of the above studies are oriented towards engineering applications. Many were carried out at intersections, and attempted to locate
deficiencies at those intersections by determining a correlation between conflicts and accidents.

THEORETICAL BASIS FOR THE PRESENT STUDY

The present study belongs to the second category of studies, investigating the behaviour of vehicles at a certain type of location - intersections.

A number of basic assumptions formed the foundation for the present study, and determined its design and research method.

1. The engineering approach necessitates the study of the normal driver and vehicle population passing through the type of location under investigation (i.e. intersections).

2. In order to develop objective criteria, the analysis should be quantitative and not merely qualitative.

3. Any unusual traffic event forms the basis for a traffic operational and safety deficiency.

4. A relationship exists between the driving stimuli that exert themselves as deficiencies and the driver-vehicle system reaction.

5. The system's reaction consists of two possible parts: a change in velocity and a change in direction of travel. Reactions are possible as acceleration or deceleration and as a change in angular velocity, or as a combination of the two, and they are interchangeable to some extent.
According to the above principles, it was decided to study the reactions and manoeuvres of vehicles on the approach to an intersection. Manoeuvres were recorded continuously, so that a microscopic model of the traffic flow could be defined in the following way:

\[ \text{reaction} = f(\text{stimulus}; \text{sensitivity}) \]

Most car-following models of this kind deal with single lane traffic on an undisturbed straight section of road, and define the reaction as a change in tangential velocity. The present model, however, deals with the interaction of pairs of vehicles on the approach to and through an intersection. In such a case, two dimensions of motion have to be considered, and all terms of the model-reaction, stimulus and sensitivity are defined accordingly.

The present study defines reaction as the resultant velocity change (deceleration), and is a function of both velocity change and directional change over time:

\[ \bar{a} = \sqrt{\frac{2}{\Delta t}} \left( \frac{\Delta s}{\Delta t} \right) \]

(1)

where:

\( \bar{a} \) = resultant change in velocity
\( \bar{a}_T \) = change in tangential velocity \( \bar{a}_T = \frac{\Delta s}{\Delta t} \)
\( \bar{a}_R \) = change in radial velocity \( \bar{a}_R = \omega s \)
\( s \) = tangential velocity
\( \omega \) = radial velocity
\( \Delta s \) = velocity change
\( \Delta t \) = time interval
Whereas the expression for the reaction can be written in a general form for any kind of traffic activity or disturbance, the terms for sensitivity and stimulus have to be defined separately for each activity.

When treating, for example, the approach to an intersection, it is suggested to use the following terms:

For stimulus:
\[ s_{n+1} - s_n; \ \omega_{n+1} - \omega_n \]

For sensitivity:
\[ \lambda_{o1} \left( x_{n+1} - x_n \right)^{-1}; \ \lambda_{o2} \left( \theta_{n+1} - \theta_n \right) \]

where:

\( n \) - leading vehicle

\( n + 1 \) - following vehicle

\( s \) - velocity

\( \omega \) - radial velocity

\( x \) - location

\( \theta \) - angle

\( \lambda_{o1}, \lambda_{o2} \) - parameters of sensitivity

It follows that the complete expression for the motion of two vehicles becomes:

\[
\ddot{a}(t+T) = \lambda_{o1} \left( x_{n+1} - x_n \right)^{-1} \left( s_{n+1} - s_n \right) + \lambda_{o2} \left( \theta_{n+1} - \theta_n \right) \left( \omega_{n+1} - \omega_n \right) \ldots \ldots \ (2)
\]

\[
\ddot{a}(t+T) = \lambda_{oo} + \lambda_{o1} \left( x_{n+1} - x_n \right)^{-1} \left( s_{n+1} - s_n \right) + \lambda_{o2} \left( \theta_{n+1} - \theta_n \right) \left( \omega_{n+1} - \omega_n \right) \ldots \ldots \ (3)
\]
The tangential expression is identical to those used in normal car-following models, whereas the angular expression is analogous and symmetrical to the tangential one.

Two formulations are offered and studied. Eq. 2 without a free term, and Eq. 3 with a free term $\lambda_{oo}$. The justification for each type of equation will be discussed later.

Other formulations to this theoretical model could probably be presented and developed.

DEFINITION OF THE DEVIATING REACTION

According to the theoretical basis developed, a potential situation of risk in traffic will form the stimulus for the driver-vehicle system, and will result in a reaction. The reaction will therefore be a subjective estimate of danger, but will be related through the equation of motion to the stimulus, which is an objective estimator.

The question arises as to what can be termed as a reaction which exceeds confidence limits of "normal" reactions, which could be defined as the white noise resulting from normal traffic conditions. At this stage, two alternative formulations of the model are considered in Eq. 2 and 3. Eq. 2 is consistent with the normal car-following theory, and implies that no reaction results when there is no stimulus. The free term in Eq. 3 implies, however, that a certain reaction may result even without stimulus. This reaction can be termed "white noise".
It is suggested to use the free term as an estimate of the 'white noise'. When the reaction to a certain motion exceeds the limits of 'white noise' by a certain amount of \( n \) standard deviations, it can be termed deviating.

\[
A \text{ deviating reaction} \quad a > \lambda_{00} + n \sigma_{\lambda_{00}}
\]

It will be shown that according to this definition, unusual events in the traffic stream can be identified.

STUDY METHOD

To evaluate the situation defined above, a stream of traffic approaching an intersection was monitored continuously. Vehicle manoeuvres were measured and evaluated. Continuous filming was considered as the most suitable method of recording. Vehicles approaching an intersection were filmed from a high building adjacent to the intersection at a rate of 24 fps. with a 16 mm. Bolex H16 camera. Before filming started, the intersection and its approaches were marked with an ortogonal grid of 1x1 meter stripes. This grid formed the basis for the analysis of the film.

The film was analyzed on a photo-optical Hadland-Vanguard film-analyzer, whereby for each film frame the coordinates of the front and rear of each vehicle were recorded. Also recorded were a sequential number for each vehicle, its type and its manoeuvre.

By means of a polynomial regression of the form \( x^n y^m \), \( (n,m = 0,1,2,3) \), the film coordinates were translated into real coordinates. In this way,
calculations could be made for each vehicle, each group of vehicles, each manoeuvre, etc. The characteristics for each vehicle manoeuvre, such as velocity, direction of travel, decelleration and angular velocity could all be accurately calculated.

Two urban intersections were selected for detailed analysis, both with similar daily traffic flows. One was a T-intersection, with reasonable geometrical layout, channelization and sight distances, and with few accidents. The second intersection, a cross-road, had many accidents during the past years. It had no traffic control, no channelization, no lane markings, deficient sight distances and parking on the approaches. It was urged that if intersection geometry has an influence on driving behaviour, it should show up in the comparison of these two locations. At the present, the study is not completed, and this paper brings results from the T-intersection only. At this intersection, 248 vehicles were filmed over 32,000 frames of 16 mm. colour film. At the second intersection, 179 vehicles were filmed, also over some 32,000 frames.

DATA ANALYSIS

The first results included a listing of the characteristics of motion for each vehicle from the moment it reached the approach until it left the intersection.

The second stage of the analysis consisted of a study of the relationship between two following vehicles, according to the models described.
Each pair of vehicles was analyzed and an equation of motion was fitted with the aid of a linear regression equation. It had to be determined what value of delay (T) between leader and follower should be chosen. For each pair of vehicles, 10 values of T were studied, ranging from between 0.25 to 2.5 seconds. The value of T selected for each pair of vehicles was taken at the point where the residual value of the regression equation was smallest. The two models, with and without a free term, were both investigated.

The third stage of analysis was to group all pairs of vehicles according to the optimal values of T obtained for each pair, and to fit a regression equation to all vehicles according to the type of manoeuvre. This stage also included calculation of the free term of the regression equation, and its standard deviation. Excessive reactions and unusual events were also determined at this stage.

RESULTS

At the intersection studied, 248 vehicles were filmed at 24 fps. and analyzed accordingly. 32 vehicles were travelling in platoons, interacted with each other, but travelled straight ahead, without turning movements.

For these vehicles, the car-following model was:

\[ \ddot{a} = 4.257 \Delta s/Hd + 0.0222 \Delta \theta \Delta \omega \quad (r = 0.92) \quad \ldots \quad (4) \]

\[ \ddot{a} = 0.096 + 3.587 \Delta s/Hd + 0.0189 \Delta \theta \Delta \omega \quad (r = 0.72) \quad \ldots \quad (5) \]
where:

\[ \Delta s = s_{n+1} - s_n ; \quad \Delta d = x_{n+1} - x_n \]

\[ \Delta \theta = \theta_{n+1} - \theta_n ; \quad \Delta \omega = \omega_{n+1} - \omega_n \]

The definition of the coefficient of correlation is calculated differently in the regression equation without a free term from the normal BMD procedure. This results in a higher correlation coefficient in eq. 4 than in eq. 5, which is, of course, unreasonable. This is one of the reasons why previously the best fitting equation was selected according to the value of the residual and not according to the correlation coefficient.

On the other hand, the two equations are not very different from each other, and produce results consistent with theory. The free term in eq. 5 contributes only little to the calculated reaction. The two other terms in each equation are statistically significant, but the first term \((\Delta s/\Delta d)\) contributes significantly more to the correlation coefficient than the second term.

According to the average value of the free term, and the standard deviation of this value, an excessive reaction was defined at two levels:

1. \( \tilde{a}_{e1} > \lambda_{oo} + \sigma_{\lambda_{oo}} \) excluding 84% of the vehicle population

2. \( \tilde{a}_{e2} > \lambda_{oo} + 2\sigma_{\lambda_{oo}} \) excluding 98% of the vehicle population
This estimate was used for a number of applications of the results, as described below.

a. To identify the vehicles that contributed the excessive values. A list was prepared for these vehicles, including their type, manoeuvres, and the values of their driving characteristics (speed, headway, etc.). These vehicles were also observed separately on the film-analyzer to study their behaviour in detail.

b. To determine average values for the "manoeuvre coefficient" of each type of manoeuvre, such as a left-turn exit from the main road, a left turn entry from the side road, stopping for a pedestrian crossing, etc.

The manoeuvres were defined according to the different types of disturbances, and are as follows:

<table>
<thead>
<tr>
<th>TABLE I. Average values of resultant braking for each type of traffic disturbance analyzed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of disturbance</td>
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<tr>
<td>---------------------</td>
</tr>
<tr>
<td>1. Undisturbed free flowing vehicles</td>
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<tr>
<td>2. Disturbance from vehicle parked on the right</td>
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<tr>
<td>3. Disturbance from preceding vehicles (platoon)</td>
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<td>4. Disturbance from platoon and parked vehicle</td>
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<tr>
<td>5. Disturbance from left turning vehicle</td>
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<tr>
<td>6. Disturbance from vehicle waiting to enter from side road</td>
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<tr>
<td>7. Disturbance from vehicle entering from side road</td>
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<tr>
<td>8. Disturbance from crossing pedestrian</td>
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</tbody>
</table>
Each type of manoeuvre can be evaluated according to its contribution to the average value of the "braking" reaction. It can be seen that left turning vehicles contribute relatively much to the disturbance (at a channelized intersection), but entering vehicles and pedestrians contribute much more. This type of analysis may form the basis for the development of more sophisticated models, calibrated for each type of intersection and type of manoeuvre, which could then be evaluated according to their contribution to the "resultant braking" reaction.

c. The preparation of charts of "iso-deceleration" at the intersection. Such charts may provide information on deficient locations within the intersection area which produce the largest contributions to the values of resultant deceleration. Such locations, once identified, can be studied on the film taken. An engineering evaluation may lead to a determination of the geometrical and traffic control improvements that could be introduced to eliminate the "black spot", (see Fig. 1).

SUMMARY AND CONCLUSIONS

This study presents a basic research effort to determine a methodology for objective analysis of traffic behaviour at an intersection. A methodology is presented to describe the motion of each vehicle, and to determine its travel characteristics. Excessive values of reaction to driving stimuli have been defined and calculated.
Fig. 1: Graphic presentation of "iso-deceleration" at intersection.
The development of two-dimensional equations of motion, the definition of unusual events, excessive reactions for each type of manoeuvre at each intersection may enable an objective analysis of vehicle manoeuvres through an intersection.

The definition of additional variables in the model and application on a wider scale may turn this method into a research tool for evaluating engineering deficiencies at intersections.

Further analysis of the data obtained, including a comparison of the "good" and the "bad" intersections, may provide further information.

It should also be studied whether similar results may be obtained by simplifying the data analysis procedures, which are, at the present, very time and labour consuming.
LIST OF REFERENCES


Hayward, J. (1971). Near Misses as a Measure of Safety at Urban Intersections. The Pennsylvania State University, Department of Civil Engineering, Pennsylvania Transportation & Traffic Safety Centre Report, U.S.A.

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