MEASUREMENT OF TRAFFIC CONFLICTS

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Abstract—Traditionally road accident statistics are used to assess the level of road safety and evaluate road safety programs. In some cases, the lack of good and reliable accident records have hampered proper analyses. A promising approach that overcomes this problem is the traffic conflict technique which relies on observations of critical traffic situations for safety analysis. However, despite the extent of work undertaken in traffic conflict research, there are still a number of issues on conflict measurement and application that have not been well understood by many safety analysts. This has resulted in a general lack of support for the wider application of the technique in safety analysis. This paper shows that one way of using the traffic conflict technique effectively is to ensure that conflicts are quantitatively defined, objectively measured and suitably applied. Before establishing the proposed framework for conflict analysis, the paper first discusses the problems and weaknesses often associated with conflict studies. Considerations for a conflict study based on the proposed approach are then presented and the case of an expressway merging is used to illustrate the method adopted.

1. Introduction

Traditionally most studies on road safety have relied on accident statistics to address a range of safety-related concerns, such as identification of hazardous locations, evaluation of safety programs or correction of irresponsible driver behaviour. Since accident occurrence is likened to a symptom of some undesirable problems in the traffic system, it is reasonable to assume that the answers to such problems can be obtained by examining the symptoms, i.e., the frequency of accident occurrence. While accident data can prove to be useful in many instances, for example, in public education campaigns to highlight driving risks, there are nonetheless several serious limitations in their usage.

In most cases, the occurrence of an accident may not be attributed to a single cause. It is rather an outcome of a complex process of interaction involving the driver, his vehicle and the road environment. Therefore, it is sometimes difficult for a traffic safety analyst to pinpoint the main causes of accidents just from accident counts alone. Moreover, even though the number of deaths from road accidents, compared to other causes of death, is still unacceptably

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high, accident frequencies segregated by locations, time and type are generally low. Given this low rate of occurrence and the statistical nature of the problem, the task of deriving statistically significant inferences by merely examining accident counts may not be an easy one. Furthermore, accidents are not always uniformly reported and this can hamper good comparative analyses. Indeed many accidents, especially those not involving any injury may not be reported at all. Hence, relying on accident reports can sometimes give rise to biased conclusions. Perhaps, the most serious objections to the traditional approach of relying on accident counts for safety evaluation and improvement is the ethical problem which requires a sufficiently large number of serious accidents to take place first, before any hazardous site or situation can be identified and corrected.

To overcome these shortcomings, many ways of employing non-accident data have been suggested (see Datta, 1979). One of the more recently used forms of non-accident information is traffic conflicts, which are defined as critical incidents not necessarily involving collisions. This idea of traffic conflicts has long been employed by highway engineers when they exercised 'engineering judgement' in identifying hazardous locations on the highways (Baker, 1977). However, it was not until the more quantitative work of Perkins and Harris (1967) that the concept of traffic conflicts was formally stated. In their landmark paper, Perkins and Harris of General Motors Corporation developed an observational procedure to test if cars of General Motors were less involved in unsafe traffic situations than those of other manufacturers. Their approach, which came to be called the traffic conflict technique, is to observe and count instances in which cars took evasive actions to avoid being involved in collisions. Such actions which presuppose the presence of critical situations, are to be identified by some observable responses made by drivers such as a sudden changing of lanes or hard braking evidenced by the appearance of the brake lights.

The application of this new technique generated immediate interest among many road safety researchers who considered the new approach as a possible complement to, if not a substitute of, the traditional approach of safety evaluation using accident data. The most appealing aspect is that conflict data can be gathered within a shorter time period compared to accident data. Thus, not only will the analysis be less affected by time-dependent factors, the ethical problem associated with the need of a long accident history will also not be an issue. The effectiveness of any safety program can also be assessed in a shorter period of time.

Recognizing the potential of the technique, many researchers have responded enthusiastically to seek ways to treat conflicts as surrogates of accidents. Initial conflict studies, such as those by Paddock (1974) and Baker (1972) highlighted the usefulness of the technique giving rise to the belief that conflicts are associated with accidents and that the technique can be used to predict accident occurrence.

However, as more researchers examined the concept of conflicts in greater detail, weaknesses in the traffic conflict technique became apparent. Objections were raised and issues related to conflict observation and analysis were also debated upon. Some researchers were sceptical of the approach (Glennon et al., 1977; Cooper, 1977; Williams, 1981) while many others (e.g., Asmussen, 1983; Grayson et al., 1984) proceeded optimistically with the design of conflict experiments as well as procedures for conflict measurement and analysis. Despite the extent of work and continued interest in the subject, as evidenced by several conferences, congresses and workshops with publications amounting to no fewer than a hundred, there are still some issues that have not been well understood. Perhaps, this may be the reason why there is a general lack of support from safety analysts to apply the technique in traffic safety evaluations.
This paper shows that one way of using the traffic conflict technique effectively is to ensure that conflicts are well defined, measured and applied. Before a framework for conflict analysis is proposed, the problems and weaknesses often associated with conflict studies are first highlighted and addressed. Considerations on the setting up of such a quantitative conflict study are then discussed with the case of an expressway merging problem serving as an illustrative example of the approach adopted.

2. Problems in conflict studies

Essentially, most of the problems associated with the traffic conflict technique stem from three fundamental and inter-related issues. They are: (1) the consistency in conflict definition; (2) the validity of the conflict technique; and (3) the reliability of conflict measurement. Most of the research work since the early conflict experiments have addressed some aspects of these issues directly or indirectly. In coming up with clearer theories to explain the processes leading to conflicts, many researchers have sought to introduce better ways to define conflicts or more rigorous methods to justify the validity of the traffic conflict technique or improved procedures to obtain reliable conflict measurements. These issues are dealt with in the following sections.

2.1. Consistency in conflict definition

In the first conflict study (Perkins and Harris, 1967), conflicts were defined based on evasive actions taken by drivers. In order that they can be easily identified, these evasive actions have to be readily observable. Thus, conflicts have been related to such instances as the appearance of brake lights or the sudden changing of lanes. Many of the subsequent conflict studies have followed the same approach but with more detailed classification of evasive actions. The insistence on regarding conflicts in terms of evasive actions may have resulted in a diversity of ways in defining, interpreting and identifying conflicts.

First of all, in order that field workers can clearly understand what is to be observed, an exhaustive list of the possible evasive actions associated with the conflict study must be specified. A study that has too many categories of evasive actions, especially those associated with complicated encounters, may impose a heavy burden on field observers, making them more prone to errors in conflict registration. Furthermore, not all the specified driver actions are necessarily evasive in nature. For example, drivers may have applied the brakes not as an evasive action to avoid a collision but rather as a precautionary action to reduce the risk potential. Differentiating a precautionary action from a truly evasive one can be difficult at times, especially when a quick assessment is demanded on the spot.

Equating evasive actions to conflicts may also present some logical problems when conflict occurrence is held as a surrogate to accident occurrence. The argument that accidents are preceded by conflicts suggests that conflicts, in terms of evasive actions, must exist prior to an accident occurrence. This assumption has often been questioned (e.g., Older and Spicer, 1976; Glauz and Migletz, 1980; Garder, 1989). It has been pointed out that many accidents and near misses have arisen largely because drivers have failed to take any action in the first place. Thus, given that evasive actions are sometimes absent in critical situations and also that some of the recorded 'evasive' actions are really precautionary ones, there may be little correlation between accidents and conflicts if the latter is defined based on observed evasive actions.
A unified definition was proposed at the First Workshop on Traffic Conflict (Amundsen and Hyden, 1977) to provide some consistency in conflict definition. It was agreed that a traffic conflict is "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged". While it does not rely on evasive actions, the definition may still have limitations since the distinction between a conflict and a non-conflict situation remains unclear in practice. The definition may have provided a common basis of thinking on and dealing with conflicts, but it also allows a wide latitude of interpretation especially in relation to what is to be considered observable and of sufficient level of risk.

Accepting this general definition of conflicts, many researchers have proceeded by imposing stricter definition specifications in their own studies. Some have investigated conflicts from the viewpoint of understanding the process leading to a collision (Brown and Cooper, 1990). The intuitive notion that conflicts are potential collisions but of a lower degree of danger suggests that a continuum representation between conflicts and accidents can be assumed. Various models have been used to describe this relationship. One such model as shown in Fig. 1, considers accidents as a subset of serious conflicts, which in turn is a subset of less serious conflicts from a universal set of exposure (Amundsen and Hyden, 1977). This representation was derived with the idea that conflicts must precede accidents. Hence, there was the theoretical argument whether collision counts should be excluded from conflict counts since they would have already been accounted for as conflicts prior to the accident occurrence.

Another form of representation (e.g., Amundsen and Larsen, 1977; Malaterre and Muhlrad, 1979a; Baguley, 1982) is in the form of an ordinal severity scale, ranging from slight conflicts to very serious ones. Theoretically, the scale can be extended to include non-conflicts in one end, as well as collisions with various degrees of severity in the other. In practice, these two extreme categories are seldom considered because non-conflict counts are irrelevant for most analyses and collisions are less likely to be observed in a conflict study.

There are two variations to this severity construct. One is the idea of a distribution function in terms of nearness to a collision proposed by Glauz and Migletz (1980) as shown in Fig. 2 and the other is a safety pyramid suggested by Hyden (1987), as shown in Fig. 3. Both concepts illustrate that non-conflicts form the major proportion of observed encounters while the observed frequency (or alternatively, probability) of occurrence decreases with increasing severity.

Although these different representations of traffic encounters can explain the concept of conflicts more precisely, the problem of inconsistency may still remain since the different
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Fig. 2. Representation of conflicts in terms of nearness to collision.

Fig. 3. Pyramidal representation of traffic events.
groups of conflicts are not clearly distinguished. Despite the many attempts to achieve uniformity in interpretation with the use of more detailed specifications, consistent definition in the different classes of conflicts has proved difficult in practice. This can be seen in a number of comparative studies (e.g., Lightburn and Howarth, 1979a; Malaterre and Muhlrad, 1979b; Muhlrad, 1982; Kraay, 1982; Asmussen, 1983; Grayson et al., 1984; Oppe, 1986b) in which different teams of observers were made to register conflicts from a common data set according to their own prescribed methods of definition. It was found that while there were good agreement in the ranking of conflict severity, there were considerable variations in the scores between the teams suggesting that there was little uniformity in defining conflicts by severity. The differences in score were also larger for the less severe cases of conflicts, implying that it was more difficult to define the less serious conflicts.

One way of overcoming the problem of ill-definition is to concentrate on using only the more serious cases of conflicts for analysis. Even so, the distinction between serious conflicts from non-serious ones (sometimes, the former is denoted as conflicts and the latter as encounters) is still unclear. In most studies, the two classes of conflicts have been differentiated qualitatively (e.g., Spicer, 1971), although Guttinger (1977) and Hyden (1977) have used time or distance thresholds to separate the two types of conflicts. These threshold values appeared to be arbitrarily prescribed. This, in part, could have explained why a different set of values were adopted in subsequent studies (Guttinger, 1982; Hyden, 1986).

Restricting conflict data to only instances of serious critical encounters also meant that a large amount of information from the larger database comprising slight and moderate conflicts is ignored. This appears to run in opposition to the intention of the traffic conflict technique, which is designed to take advantage of more extensive information available in conflicts instead of relying on limited accident data.

2.2. Validity of traffic conflict technique

Validity of the traffic conflict technique is often judged by the adequacy in the correlation between observed conflict counts and accident records. This stems from the long-accepted practice of relying on accident data for safety evaluation. The validity issue became a topic of intense debate when a good number of conflict studies failed to show an acceptable level of statistical correlation between conflicts and accidents. Part of the validity issues and problems is due to inaccurate, unreliable and under-reporting of accidents themselves (Grayson and Hakkert, 1987).

Some researchers, for example, Glennon et al. (1977) and Williams (1981), have seriously questioned the usefulness of the technique and called for a reassessment of the entire concept of traffic conflict, claiming that for every case of good correlation, there was another of poor correlation. Without rejecting the technique totally, some others, (see Baker, 1972; Amundsen and Hyden, 1977), however have recommended a more restrictive use of the technique to cases where accident counts are too low for traditional accident analyses. On the other hand, a good number of researchers, such as Oppe (1977), Zimolong (1979), Hyden et al. (1982), Baguley (1982) and Muhlrad (1982), who assumed the validity of the method, have sought either to improve the correlations by redefining conflicts or explain the poor correlations between conflicts and accidents. Some like Hauer and Garder (1986) and Grayson and Hakkert (1987) have chosen to address the issue of validity more fundamentally rather than merely seeking a good statistical correlation between conflicts and accidents.
Part of the problem in establishing a correlation between conflicts and accidents lies in the nature of conflict and accident data, both being subjected to statistical variations as well as some amount of unreliable measurements. Hauer (1979) well noted that “the persistent fog hovering over this issue (of validity) stems from carelessness in defining what unsafety is”. Thus, even if there is a definite correlation between accidents and conflicts, it would be the expected (i.e., the true value) and not the observed accident and conflict rates that are correlated. The estimation of the true rates using observed values is fundamentally not robust given that the sample sizes are usually small and the factors influencing the two sets of data are not necessarily similar.

Oppe (1986a) has further argued that it is necessary to classify conflicts and accidents according to manoeuvre types as well as severity levels to examine correlations consistently. This point can be illustrated from the results of one study (Guttinger, 1979) which showed that correlation between conflicts and accidents at the study site improved when cyclist–pedestrian conflict counts were excluded; the reason being that there was no record of cyclist–pedestrian accidents. However, segregating conflicts and accidents will reduce the sample sizes and this may make comparison between the two variables even more difficult.

Given the uncertainties over the quality of accident and conflict data and the many contributing factors that are unaccounted for, it may be a futile exercise, and possibly an unnecessary one as well, to insist on establishing a statistically acceptable relationship between conflicts and accidents to justify the use of the traffic conflict technique. Indeed, it seems that such a relationship is only required if conflict studies are intended to predict accident occurrence. The idea of predicting accidents was opposed by Hauer (1979) who contended that the greater need in safety studies is to prevent an accident rather than to predict one. Hence, the traffic conflict technique should be used mainly as a diagnostic and evaluative tool rather than as a predictive one. This means that validating the technique based on its predictive ability may be unnecessary.

On statistical methods, Hauer and Garder (1986) have argued that the validity of the traffic conflict technique is best judged by comparing the variance of the estimates in rates in conflicts and accidents rather than comparing the estimates themselves. Since validity is a matter of degree rather than absolute, it follows that the most valid method is one that produces an unbiased estimate with the smallest variance.

Grayson and Hakkert (1987) have further reasoned that validity is not confined to an explicit demonstration of an adequate relationship between conflicts and accidents alone, even if all the problems associated with establishing such a relationship can be satisfactorily addressed. They have argued for the case of ‘construct’ validity based on the common causation process that leads to the different possible outcomes of conflicts or accidents rather than on statistical validity based on a comparison between the outcomes. Naturally, this means that validity is to be judged by how well the conflict analyses can be used to identify safety and operational deficiencies as well as to evaluate safety and operational improvements in the road system.

2.3. Reliability in conflict measurements

The method of conflict measurement has been one of the major concerns in all conflict studies. Many of the early studies have been designed based on the notion that conflicts must be observed and conveniently measured in terms of the actions of drivers. In many studies, conflicts were subjectively treated. Some of them have considered conflicts to be objectively
measured when these conflicts could be clearly identified as in the case of the appearance of the brake lights. This, however, is misleading since this has more to do with objective definition than objective detection or measurement.

Subjective treatment of conflicts may bring about the possibility of unreliable measurements, although such uncertainties can be treated by careful application of statistical analyses. There are generally two aspects of unreliability in such measurements. The first arises out of inconsistency in recording made by an individual observer and this is sometimes called intra-rater variation. The second is due to variability in interpretation and recording of a given situation between different observers or inter-rater variation. Several researchers such as Glauz and Migletz (1980) and Guttinger (1982), have classified the first as a ‘consistency’ problem while the second, a ‘repeatability’ problem.

An individual observer may inconsistently detect conflicts for a variety of reasons. Poor definition as well as excessive and complex conflict types may produce unreliable readings. Human factors such as fatigue and lack of training can also affect conflict readings significantly (see Older and Spicer, 1976; Malaterre and Muhlrad, 1977; Lightburn and Howarth, 1979b; Muhlrad, 1982). On-site observations, in contrast to filmed recordings, are also more prone to errors which cannot be verified subsequently. To overcome some of these problems, several countries involved in extensive conflict research have developed manuals and training packages (e.g., Hauer, 1987; Glauz and Migletz, 1980; Swain, 1987; Parker and Zegeer, 1988, 1989; Pfleger, 1993; Hummer, 1994) detailing the various types of conflicts and the observation procedures required.

Several comparative studies have also been undertaken in an attempt to unify the different methods of conflict observation and to ensure that a conflict experiment is repeatable. The first international study, carried out at Rouen in Paris in 1979 with the participation of four teams of observers (Malaterre and Muhlrad, 1979a,b), showed that the severity scale adopted by the different countries was not uniform thus resulting in differences in conflict detection rates. A full-scale conflict study (Grayson et al., 1984) involving traffic safety workers from 12 European and North American countries was undertaken at Malmo in Sweden in 1983. In this experiment, both on-site and video observations were made. The results again showed that there were considerable variations in the conflict recordings observed by the different teams. Although observers generally evaluated conflict severity in the same order, differences in conflict detection rates among the different teams were apparent. All these show that uniqueness in measurements may not be guaranteed and the variation in measurements may be affected by the way conflicts are defined and observed. This can be a problem if the variations are high.

Even when conflicts are well defined and observers well trained, subjective treatment of conflicts may still result in significant variations in observation. On-site observations suffer from the disadvantage that they are difficult to verify. Video recordings can facilitate repeated viewing but they do not provide the same quality of observation as a human observer on site. Where subjective measurements are used, observers are more likely to make better judgement from on-site interpretation of simultaneous events than from a limited two-dimensional, sequential view of video images.

While most conflict studies involved some form of conflict counts based on subjective observations of traffic interactions, there have been a few which made use of more quantitative measurements, in terms of time and space proximity between vehicles. Hayward (1972) have measured the severity of conflicts as the time to-collision, or the time taken by the conflicted vehicle to collide into the offending vehicle if the speeds and paths of the both
vehicles remained unchanged. Since time-to-collision can vary throughout the interaction process, van der Horst (1990) has also considered different points at which time-to-collision should be measured. The time-to-collision at the onset of braking (sometimes called time-to-accident) and the minimum registered value of time-to-collision in an interaction process are two of the most commonly used quantitative measures in conflict analyses.

Other time measures, have also been proposed for cross traffic and single-vehicle interactions. In their studies, Allen et al. (1978) and Cooper (1983) have employed gap time (the would-be time difference between arrival of the involved vehicles at the point of crossing if no evasive actions are taken) and post-encroachment time (time difference between arrival of conflicted vehicle and departure of offending vehicle at the point of crossing) for measurement of conflicts between crossing vehicles. van der Horst (1990) has also used time-to-intersection, which is the expected elapsed time for a vehicle to enter the intersection at constant speed at the onset of braking, to analyze conflicts at intersections.

The use of these quantitative measures has not been widely used, largely because the data extraction process is rather time-consuming. However, there are indications that the data extraction process can be made less labour intensive with increased use of computer technology (van der Horst, 1989; Almqvist, 1989; Svensson and Odelid, 1993). The use of quantitative measures should be promoted.

3. Proposed framework for a traffic conflict study

Having examined the problems associated with conflict studies, it is now possible to propose a framework whereby the traffic conflict technique can be applied effectively in studies targeted at examining traffic interactions. It appears that many of the problems associated with conflict studies, particularly those related to inconsistent definitions and unreliable measurements, can be resolved if conflicts can be treated more objectively and precisely. This approach may also enable a better comparison of results between different studies. However, there are several important requirements if conflicts are to be studied in this manner. Firstly, conflicts must be quantitatively defined. Secondly, observation of such conflicts must be measurable. Thirdly, conflict measures so derived and observed must be suitably applied. These are further elaborated in the following sections.

3.1. Quantitative definitions

Conflicts used in the proposed framework must be so defined that they can be evaluated objectively. While there is value in using qualitative definitions, quantitative definitions can produce more objective evaluations. Furthermore, the definitions adopted should reflect correctly the intended purpose for which conflicts are observed. Thus, if conflicts represent irritations in the traffic system, as suggested by Hauer (1979), and the study of conflicts is aimed at identifying safety deficiencies or correcting inherent operational problems of traffic safety in the road system, then the definition should be related to the cause of the irritations and the lack of safety. It is therefore more appropriate to choose conflict definitions that need not rely on the observed action of the conflicted drivers since the presence of any danger may not be dependent on whether they react to it or not. On the other hand, if the purpose of the conflict study is to deal with safety deficiencies in driver behaviour in specific roadway or environmental conditions, it would be more appropriate to define conflicts in terms of the
response or the lack of anticipatory actions of the drivers. In either case, it is better to have conflicts that are defined in quantitative terms.

A good example of defining conflicts quantitatively is to represent conflicts as the nearness to a collision defined in terms of either space or time proximity between interacting vehicles. The closer the vehicles are to each other, either in time or space, the nearer they are to a collision, which occurs when both the time and space separations vanish simultaneously. The advantage in this definition is that all collisions will be preceded by conflicts. Furthermore, regardless of the measurement procedures, a common basis for comparison can be accomplished without an elaborate structure of defining the severity of the conflicts. The greatest appeal in using either a time or space proximity definition is that it is easily understood and appreciated by both drivers as well as conflict observers, thereby avoiding the problems commonly associated with philosophical definitions.

3.2. Measurable observations

Having derived a general but quantitative way of defining conflicts, it is necessary to select those definitions that can be easily observed and measured. As an example, conflicts defined by time proximity may be better than those defined by space proximity. This is because, while judging short distance between objects when they are stationary can be done quite accurately, it is quite difficult to judge distances between objects in motion. This makes on-site measurement of space separation between interacting vehicles a difficult task, if not an impossible one. On the other hand, time measurement is more straightforward and the scale of measurement is nearly continuous so that arbitrary grouping of conflicts becomes unnecessary.

Measurement of quantitatively-defined conflicts requires more effort than qualitative ones so that on-site observations of the former can only be done under low flow conditions. Moreover for any conflict encounter, the conflict, whether defined in terms of time or space measurements, will vary throughout the encounter so that continual monitoring may become necessary. Given such limitations, it is unlikely that objective measurement of conflicts can be done efficiently using human observers on site.

To overcome the problems associated with on-site observations, methods of recording conflict encounters for subsequent observation and measurements must be sought. Although it is possible to record conflicts with various sensors on the road or at the roadside, most conflict recordings are done using cameras which allow conflict events within a suitable span of space to be recorded over a desired duration of time. In the past, time-lapse cameras have been used to record traffic interactions. With the emergence of video technology, video recording has virtually replaced time-lapse photography in conflict analysis. Since video recordings are done at fixed time intervals, usually at 24 frames per second, time measurement which is analogous to counting the number of frames advanced can be done with good precision.

3.3. Suitable applications

Besides being well defined and properly measured, the selected conflict measures must enable appropriate and meaningful inferences to be derived from the analysis. Thus far, the issue of ensuring suitable applications seem not to be well addressed in most conflict studies. If a conflict analysis is to be used to diagnose safety problems in the traffic system, then the observed conflicts should reflect correctly the state of the traffic system with regards to these problems.
Like accidents, the different types of conflicts are outcomes of a complex mix of factors and causes. In pursuing a detailed analysis of conflicts, it is necessary to appreciate the likely causes of conflicts which the conflict study is designed to measure. Obviously there are many factors which may not be directly related to the hazardous condition under investigation. The advantage of identifying suitable conflict applications is that specific conflict problems can be isolated and studied more closely.

For example, conflict analyses involving the examination of interaction of traffic may not be useful in investigating problems like drunken driving. Indeed few conflict studies, if any, have defined conflicts in a manner that can adequately represent drunken driver behaviour. Quantitative definitions based on time or space proximity measures, as proposed earlier, are most useful in tackling safety problems associated with changes in vehicle kinematics in the stream such as hazards of speeding and skidding.

In identifying the critical situations corresponding to the hazardous conditions to be studied, it is necessary to specify the threshold value of the conflict measure distinguishing the critical situations from the non-critical ones. This threshold should not be chosen arbitrarily but should be derived in accordance to the nature of the hazards to be investigated. For example, if the problem of skidding is to be examined, then the threshold values should be related to the limiting skid friction. Furthermore, since the likelihood of observing such a critical situation is low and based on limited sample size, it is sensible to establish a statistical distribution of the conflicts so that the proportion of critical situations are not merely counted but derived mathematically. This is illustrated in Fig. 4 which shows a probability function of a generalised conflict severity measure derived from observations of the quantifiable conflict measure. Once a suitable threshold is ascertained, the proportion of critical conflict situations can be determined by evaluating the area under the conflict curve beyond the threshold value. The application of this technique will be further illustrated with a specific example in the following section.

The approach outlined above makes use of kinematic conditions to define, measure and apply conflicts and this is particularly suitable for those conflict studies involving vehicle interactions. Clearly hazardous situations can arise due to other causes, e.g., a vehicle
negotiating a sharp bend in the absence of other vehicles or a driver using a handphone on a perfectly safe road. In such cases, kinematic conditions may not be sufficient to define and measure the conflicts. The characteristics of the roadway environment, the vehicle system and the driver's attitude and state of mind may become important factors which must be taken into account in the conflict definition and measurement. In any case, the intent of the conflict study should dictate the choice of the conflict definition, the procedure of conflict observation and the manner of conflict application.

4. An illustration of conflict application

The application of the traffic conflict technique based on the framework proposed is now illustrated for the case of an expressway merging situation. In the expressway merging problem, the introduction of flows from the on-ramp into an expressway creates turbulence in the expressway traffic and this may give rise to critically dangerous situations.

To investigate this hazardous condition in the merging area, a conflict study was designed to assess the probability of occurrence of a serious conflict due to a merging situation on an expressway (Chin et al., 1992). Instead of adopting the usual practice of qualitatively defining conflicts and their severity and then counting the number of such conflicts observed, the method defines conflicts rationally based on some known causes of the hazardous situation and then computes the probability of conflict occurrence by making use of all conflict information gathered in the field. Only the conceptual development of the method is discussed here. Detailed descriptions of the study, including its mathematical derivations, data collection and error estimation are given in Chin et al. (1991).

Two possible hazardous situations arising from the interactions between the traffic streams may be envisaged. First, a hazardous situation can arise when a mainline (expressway) vehicle reacts insufficiently in response to a merging vehicle so that it crashes into the merging vehicle. The second hazardous situation can arise when the mainline vehicle reacts excessively to the extent that the driver loses control of the vehicle due to skidding. In the two hazardous situations identified, only the primary effects of merging are considered. Secondary effects, such as the turbulence in the traffic stream caused by the reaction of the mainline vehicle to a merging vehicle, are not included. Clearly the two situations identified do not represent all hazards in the merging problem but only those that the study seek to investigate. Depending on the purpose of the study, the scope of the merging problem can be broadened by identifying other hazardous situations and if needed, by modifying the conflict definition and observation procedure.

4.1. The hazard of insufficient reaction

A vehicle crashes into another if the driver reacts inadequately to the vehicle in front. To avoid this hazardous situation, a driver continually monitors the movement of his vehicle in relation to the vehicle in front and reacts by braking when an accident becomes imminent. However, there is a time lag between the perception of this hazardous condition and the application of the brakes. This lag is governed by the driver's reaction time and may vary from a fraction of a second to a few seconds, depending on a number of factors such as his skill, experience and emotional state.
The conflict encountered under this hazardous condition can be defined quantitatively by the time-to-collision, which is the time taken by the trailing vehicle to crash into the front vehicle, if the vehicles continue in the same path without adjusting their speeds. Naturally, this condition will arise only if the speed of the trailing vehicle is higher than that of the leading vehicle. Furthermore, the greater the difference in speeds or the smaller the spacing between the vehicles, the shorter will be the time-to-collision and hence the more serious the conflict. Therefore, the time-to-collision also quantitatively specifies the severity of the conflict. However, since time-to-collision decreases with increasing severity, it would be better to represent the conflict measure in terms of the reciprocal of time-to-collision, which increases with increasing conflict severity. This definition also spells out the condition at which a conflict ceases (i.e., when the reciprocal of time to collision becomes zero).

Chin et al. (1991) have shown how kinematic data of vehicles involved in the merging manoeuvres can be obtained. Traffic movements within the merging area of the study site were first recorded on video films and kinematic information of vehicles were then extracted by noting the time and position of the vehicles during the video playback. Values of time-to-collision throughout the merging interaction process were computed for each pair of vehicles. A statistical distribution which can suitably describe the reciprocal of time-to-collision values observed was then derived, namely, the mixed Weibull density function. A typical distribution obtained from the field study in Chin et al. (1992) is shown in Fig. 5. The probability mass function when the reciprocal of time-to-collision is zero corresponds to the fraction of merging events with no conflict, which is not plotted.

Fig. 5 shows that a large proportion of these conflicts will not be serious, since the time-to-collision will be much greater than the reaction time of the drivers. If the reaction time of all drivers is a constant value, say 1.0 second, then the probability of a conflict due to insufficient reaction will be obtained from the area under the inverse of time-to-collision curve right of the reciprocal of reaction time value of 1.0 second. Since the reaction time will be different in a population of drivers, it is more appropriate to consider a distribution of reaction times such as the one obtained by Johansson and Rumar (1971). Given the two statistical distributions, it is possible using numerical integration, to derive the probability of having a
case when the time-to-collision is less than the reaction time of a driver. For the site studied (Chin et al., 1992), the probability of having a conflict where the reaction time exceeds the time-to-collision was found to vary from 4 in 100,000 to 5 in 10,000 for the different periods of surveys undertaken.

4.2. The hazard of excessive braking

While a driver may avoid a potentially dangerous situation by braking his vehicle, he may fall into another hazardous situation by over-braking. Hard braking is particularly dangerous when the quality of the road surface is poor, that is the skid resistance of the surface is low.

The conflict representing this hazardous situation can be specified quantitatively as the deceleration-to-avoid-collision. This is defined as the uniform deceleration that a vehicle will require just to avoid contact between the vehicles, if the front vehicle does not change its course and speed. Mathematically, deceleration-to-avoid-collision is directly proportional to the square of the relative speed and the reciprocal of clear spacing between the vehicles. As in the case of time-to-collision, a conflict does not exist when the speed of the trailing vehicle is lower than that of the leader. This quantitative measurement also reflects the severity of the conflict since the higher the value of the deceleration, the more serious is the conflict.

Again, using the observed kinematic data of vehicle interactions, a statistical distribution of the deceleration-to-avoid-collision can be derived. Fig. 6 shows the distribution of deceleration-to-avoid-collision corresponding to the same set of observations in Fig. 5.

A potentially hazardous situation will develop and the vehicle will skid when the required deceleration exceeds the skid resistance on the road, which is affected by the quality of the vehicle tyre, the degree of polishing of the road surface and the presence of loose substances or liquids between the tyre and the pavement surface. A series of skid resistance measurements were made at different spots on the road under dry surface conditions and a statistical distribution of skid resistance values derived. As before, by considering the distribution of conflict values based on the deceleration-to-avoid-collision and the distribution of skid values, the proportion and hence the probability of occurrence of a hazardous situation due to skidding can then be computed. For the same site studied, the probability values were found to range from about 7 in 100,000 to 6 in 10,000 for the different periods of observation.
5. Discussion and conclusion

The foregoing shows how conflict measurements obtained quantitatively can be used to derive useful inferences on the state of safety in a system. Comparison of safety levels between different time periods and operating conditions (such as day and night conditions or dry and wet surface conditions) or between different localities can be made once specific probabilities of conflict occurrence are obtained. Before-and-after studies can also be evaluated efficiently and quickly using the same procedure.

This paper has shown that some of the misgivings in the traffic conflict technique are unfounded and most of them may be tackled by defining and measuring conflicts objectively and quantitatively. Designed carefully, the traffic conflict technique when applied to address specific safety problem can yield useful results which may be impossible to obtain using traditional accident analyses. The proposed procedure to consider conflicts quantitatively is properly structured, though it may also be time consuming and labour intensive.

Fortunately, recent developments in image processing (Svensson and Odelid, 1993) may offer some promise in automating the labour intensive procedure of kinematic data extraction. However, most of the existing image processing systems used in traffic engineering applications are still not suitable for quantitative conflict analyses because they have been designed primarily to obtain aggregated traffic information such as flow counts and traffic speeds rather than kinematic information of individual vehicle movements. A major part of the problem lies in the poor quality of the video images arising from imprecise vehicle images, which are very much affected by variable lighting conditions at the site as well as background noise due to non-vehicle interference. All these will naturally influence the accuracy of conflict measurements which is crucial for a quantitative study. Nonetheless, given the rapid changes in computer imaging and video technology, the emergence of a suitable image processing system for conflict study within the next few years may not be surprising.

References


