LUND UNIVERSITY

Deliverable No. 2 – Review of Literature and Experience on the Application of Conflict Studies to Rural Roads. Working report within the project Conflict Study – Application in HA (Highway Agency) Road Safety Management

Svensson, Åse; Carsten, O

2007

Link to publication

Citation for published version (APA):
Svensson, Å., & Carsten, O. (2007). *Deliverable No. 2 – Review of Literature and Experience on the Application of Conflict Studies to Rural Roads. Working report within the project Conflict Study – Application in HA (Highway Agency) Road Safety Management*. Highways Consultancy and Research Group.

Total number of authors:
2

General rights
Unless other specific re-use rights are stated the following general rights apply:
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.
• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal

Read more about Creative commons licenses: https://creativecommons.org/licenses/

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Highways Research Group

Conflict Study - Application in Highways Agency Road Safety Management

Deliverable No. 2
Review of Literature and Experience on the Application of Conflict Studies to Rural Roads

Åse Svensson, Department of Technology and Society, Lund University
Oliver Carsten, Institute for Transport Studies, University of Leeds

Contract Reference: 3/387

HA Task Reference: 200(387)MTSC – Scott Wilson

Project Sponsor: Sandra Brown

Company Details

Highways Research Group (HRG) are a multi-disciplinary supply chain comprising over 30 diverse organisations, strategically designed to meet the technical research needs of the Highways Agency (HA). The Group behaves as a community, sharing knowledge and working in partnership with the HA. Research and Development Framework Tasks are managed through the Contract with Scott Wilson Limited.

The nominated Project Director is: Prof Robert Armitage - Director
Organisation: Scott Wilson
Tel: 0115 9077003
Fax: 0115 9077001
Email: robert.armitage@scottwilson.com
Address: 12 Regan Way, Chetwynd Business Park, Chilwell, Nottingham, NG9 6RZ.

The nominated Project Manager is: Bill Gallear – Technical Director
Organisation: Scott Wilson
Tel: 01629 761763
Fax: 01629 761789
Email: bill.gallear@scottwilson.com
Address: Dimple Road Business Centre, Dimple Road, Matlock, Derbyshire, DE4 3JX

The nominated Assistant Project Manager is: Dr Edwin Barker – Senior Engineer
Organisation: Scott Wilson
Tel: 0115 9077037
Fax: 0115 9077001
Email: edwin.barker@scottwilson.com
Address: 12 Regan Way, Chetwynd Business Park, Chilwell, Nottingham, NG9 6RZ.

The Research and Development Framework Contract Manager is:
Alistair Hunter
Tel: 0115 9077031
Fax: 0115 907 7001
Email: alistair.hunter@scottwilson.com
Address: Scott Wilson, 12 Regan Way, Chetwynd Business Park , Chilwell, Nottingham, NG9 6RZ

Registered office: 12 Regan Way, Chetwynd Business Park , Chilwell, Nottingham, NG9 6RZ

The company is registered in England & Wales: No. 1910469

© 2007 Highways Consultancy and Research Group

Executive Summary

This report reviews the literature and practical experience with assessing the safety performance of rural road locations using the traffic conflicts technique. It provides an overview of the development of conflict studies, which have overwhelmingly been applied at urban locations. It also discusses the current state of the art in the application of automated video analysis for the detection of conflicts. Recommendations are made on the data collection methods and conflict definitions that should be employed for applying conflict studies at rural locations.

© 2007 Highways Consultancy and Research Group

Contents

© 2007 Highways Consultancy and Research Group

1. Introduction

This report is part of a wider study, the aims of which are to:

- establish reliable relationships between accident and conflict data, pertinent to different situations on the Highways Agency network
- widen the scope of previous work to consider specific junction types, including rural junctions, and to consider the applicability of conflict techniques to links
- compare actual accident data with prediction using conflict study and SafeNET software, which is now applicable to rural as well as urban roads
- test the use of Conflict Study techniques and determine suitability for use by Road Safety Engineers for assessing safety at specific locations on the network
- develop guidelines on the use and methodology applicable for Conflict Studies

This report is intended to review:

- the applicability of the conflict technique to rural intersections
- identifying any uses of Conflict Studies on links (as opposed to junctions) and lessons learnt.

A key identified issue is the state of the art regarding automatic video analysis of road user behaviour, which may be particularly relevant to links.

© 2007 Highways Consultancy and Research Group

2. Overview of Conflict Studies

2.1 Introduction

The development and application of traffic conflict studies goes back to the 1960s. Conflict studies have been used in a variety of ways:

- As a research tool to improve understanding of the relationship between behaviour and risk (with conflicts as the risk indicator)
- As a method for safety diagnosis — understanding the nature of safety problems at a site or series of sites
- As a tool for evaluating safety changes, where statistical reliability might require several years of before and after accident data, but where counts of conflicts can provide reliable evaluation with only days' worth of data
- As a substitute for accident data in places (e.g. less developed countries) where accident data is either non-existent or extremely unreliable.

Conflict studies have the inherent advantage over accident studies that conflicts are generally observed *simultaneously* with the surrounding events and conditions. Where manual observation is used, as has traditionally been the case, the observer can witness the conflict events unfolding in real time and can therefore identify and record the precursors to the conflict. Where video is used as the source of information or to supplement the manual observer, then the video also provides information as the conflict situation develops. Accident data, on the other hand, is very rarely collected in real time; normally accident investigation and reconstruction takes place post hoc.

Conflicts are far more frequent than accidents, and therefore can potentially provide reliable information in situations where accident numbers are insufficient. An indication of the relative frequency of traffic events is shown in Figure 1. Undisturbed passages are those situations where there is no interaction between the various road users, an example being free-flow traffic.

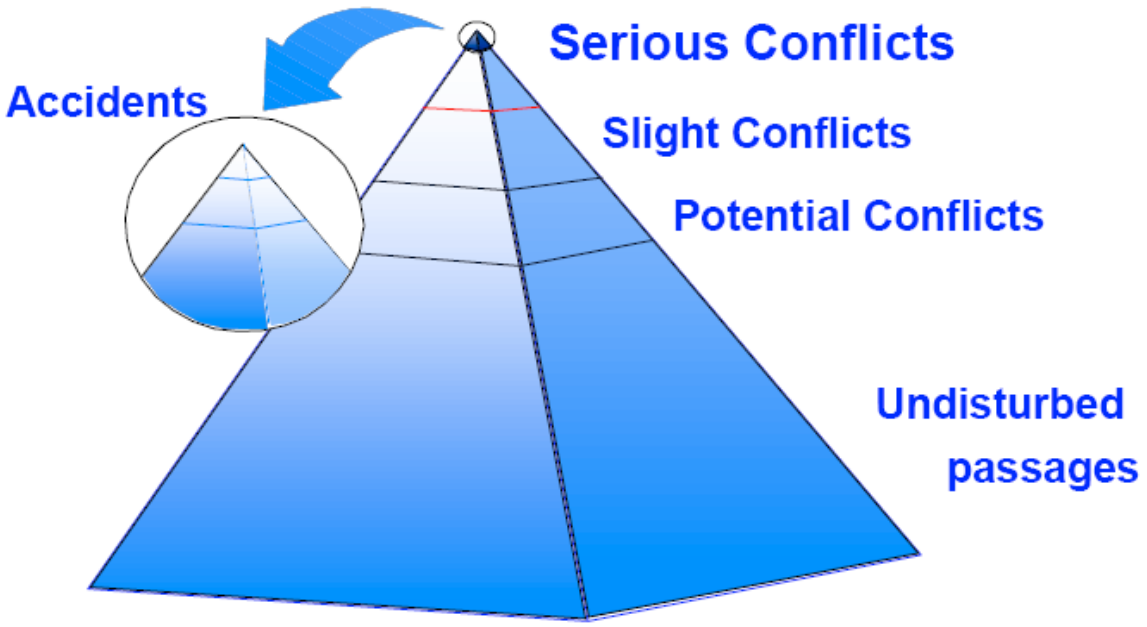

Figure 1: The safety pyramid (Hydén, 1987)

Above those undisturbed passages are the situations where there is some interaction between road users. These are sometimes termed "encounters", and they can be defined as situation where one road user has to adjust his/her progress when faced with the progress of another road user. Beyond these are the conflicts, divided in some way according to their severity, and finally we have the relatively small number of accidents, again divided by severity.

© 2007 Highways Consultancy and Research Group

An international workshop held in Oslo in 1977 produced an agreed definition of a traffic conflict (Amundsen and Hydén, 1977):

> 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 remain unchanged.

It should be noted that, by definition, there are no single-vehicle only conflicts, so that safety problems related to, for example, single vehicle run off the road accidents or single vehicles colliding with fixed objects are not covered by the conflict technique.

2.2 Variety of conflict techniques

The first reported use of a formal conflict technique is by Perkins and Harris (1967 and 1968). The technique was applied by them at urban intersections with a view to ascertaining whether General Motors cars performed more safely than those of other manufacturers. Conflicts were defined as those events involving swerving, braking or traffic violations. There was no scaling of conflicts by severity.

Most subsequently developed definitions have adopted some kind of severity scaling. An example can be found in the two UK versions that of Older and Spicer (1976) and that of TRRL (1987).[1] The latter uses four factors to grade severity:

A. Time to collision (short, moderate or long)
B. Severity of evasive action (light, medium, heavy or emergency)
C. Complexity of evasive action (simple or complex)
D. Proximity of conflicting vehicles (>2 car lengths, 1–2 car lengths or <1 car length)

Scores on each of these are combined to create four severity grades. Other versions of the Traffic Conflict Technique (TCT) such as those developed in Germany and France have also divided conflicts according to severity (Lord, 1996).

In the 1980s there was a strong tendency to move from somewhat qualitative definitions of conflict thresholds and severity towards quantitative definitions. Two measures of movement in space and time were generally applied:

> Post Encroachment Time (PET): this is the time between the first road user exiting from the conflicting space and the second road user arriving in that space.
>
> Time to Collision (TTC): this is the time that will elapse before the two road users collide unless one of them takes an avoiding action (e.g. by braking, swerving, or in the case of a pedestrian stopping or stepping out of the way).

TTC is now far more commonly used that PET, in part because of theoretical issues (road users are not by definition on a conflicting path with PET) and in part because of issues with reliability (see e.g. Lord, 1996), who found that PET measures could not be correlated with accidents because they were too scattered. However, when used in the field, there tends to be broad agreement between the various techniques in defining certain events as conflicts, particularly at the more severe end of the scale. This general agreement between the various approaches was confirmed in the Malmö calibration study carried out in 1983 with teams from 23 countries participating (Grayson et al., 1984). This study confirmed that TTC rather than PET was the common index of severity. The overall conclusion from the study was that, while there were substantial disagreements between the teams as to whether some events were conflicts or not, this was far less of a problem when severity was taken into account:

> The results of the data analysis show that there is a good degree of agreement between most of the techniques calibrated in Malmö: all of them operate on the basis of a common concept. Once conflicts are detected the level of agreement is particularly high, particularly for the more serious conflicts (pp 89–90).

[1] Note that there have not been any new UK versions of the technique since 1987.

© 2007 Highways Consultancy and Research Group

The Swedish TCT, developed at Lund University, from the very beginning encompassed:

1. A quantitative definition of a conflict using TTC, and
2. A distinction between slight and serious conflicts

TTC was registered by the conflict observer at the moment that one of the parties involved in the conflicting even took some kind of evasive action (Hydén, 1987). TTC at that moment was termed Time to Accident (TA) and TA was defined as the time remaining from when the evasive action is taken until the collision would have occurred *if* the road users had continued with unchanged speeds and directions. The TA value can be calculated based on the observer's estimates of distances d and speed v, where:

d = Distance of the "relevant" road user (= evading road user) to the potential point of collision at the moment when evasive action is taken

v = Speed of the relevant road user at the moment when evasive action is taken

It is important to note that here the speed of only one participant — the road user who takes the evasive action — is taken into account in determining conflict severity.

In Hyden's initial grading of severity a single TA value of 1.5 seconds was used to define the boundary between slight and serious conflicts: below 1.5 seconds meant serious. This was subsequently refined to a boundary that took the speed of the relevant participant into account a second time. This was based on the theoretical consideration that with a vehicle travelling at high speed a TA or TTC of even several seconds might not be adequate for the vehicle to brake severely without a subsequent collision, while at low speeds a value of 1.5 seconds might not be particularly serious. The borderline between slight and serious conflicts was therefore defined in terms of the deceleration capability of a car under severe braking. Subsequently an additional fixed safety margin of 0.5 seconds was added. This resulted in the definition as shown in Figure 2.

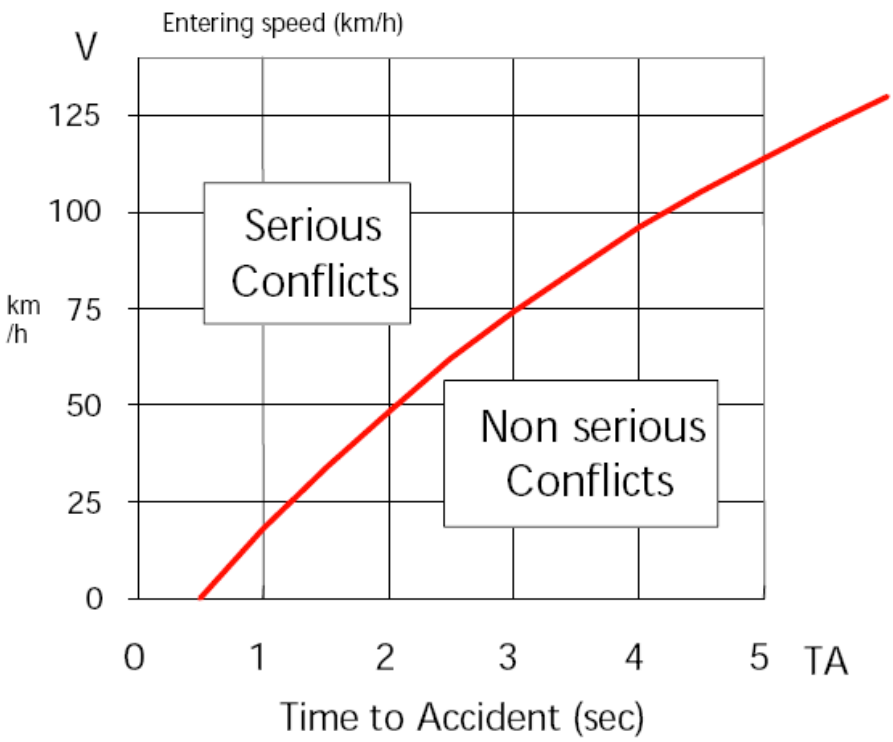

Figure 2: Severity in the Swedish Traffic Conflicts Technique (TCT)

The Swedish TCT has been in continual use since the 1980s both in Sweden and more widely. It has been used in the UK, Denmark, Finland, Norway, Turkey, The Netherlands, France, Hungary, Portugal, Brazil, Argentina, Uraguay, Bolivia, Chile, Jamaica, Costa Rica, Panama, Tanzania, Uganda and Jordan. Primarily it has been applied for research, but it has also been used by highway authorities, particularly in Sweden, as a diagnostic and evaluation tool.

© 2007 Highways Consultancy and Research Group

2.3 Validity of the traffic conflicts technique (TCT)

The validity of the TCT has been hotly debated, with the most contentious area being the relationship between conflicts and accidents and the expectation that there should be a numerical correspondence in the form of a high correlation ratio between numbers of observed conflicts (usually but not always serious conflicts) at a set of sites and numbers of recorded injury accidents at those same sites. Thus Williams (1982) concludes that the validity of the TCT is in serious doubt.

Although some studies (e.g. Spicer, 1973) have found good correlations between conflicts and accidents (particularly so between serious conflicts and injury accidents), there has also been criticism of the approach of looking for such correlations. It is well known that accidents in a given year are not a good indicator of the Underlying True Accident Rate (UTAR, i.e. long-term annual mean of accidents) at a site. Similarly, observed numbers of conflicts over a period of days will only provide an estimate of what can be termed the Underlying True Conflict Rate. Variability in both rates is governed by a Poisson process, with variance equal to the mean. Thus Migletz, Glauz and Bauer (1992) concluded that the application of regression analysis or correlation coefficients in the analysis of the relationship between conflicts and accidents was inappropriate. Instead, the proper use of conflicts would be to estimate the *expected* rate of accidents, i.e. the UTAR. The overall conclusion from that study is that particular types of conflicts at both signalised and non-signalised intersections make as good predictions of mean accident rates as do reported accident numbers. Muhlrad (1993) states: "Validation studies showed that conflicts were a better predictor of future unsafety than accidents themselves where these were in small numbers, particularly as regards pedestrian accidents." Hauer and Gårder (1986) argued for a new definition of validity in which rather than having some absolute definition of validity, validity was a matter of degree which could serve as a yardstick to judge the quality of a particular conflict technique. Lord (1996) investigated conflicts between left-turning vehicles and pedestrians and examined the relationship between those conflicts and the expected number of accidents at eight sites in Hamilton, Ontario. He found that the relationship did indeed differ depending on the conflict technique applied.

A further issue in the validity of the TCT is the similarity between the events detected by the conflict observers and the recorded data in police-reported accidents. In the Malmö study it was noted that there was a general congruence between the conflict types and the accident types, and some indications that conflicts accorded better with injury accidents than with all accidents (Grayson et al., 1984). In a very detailed comparison of safety indicators, conflicts and accidents at four four-way intersections in Stockholm, Archer (2005) found that the relationship between conflicts and accidents was very strongly affected by differences in signalling regime. In the case of one interaction — opposing left turns off the main street — conflicts were identified but there were no corresponding accidents. From his study of safety indicators at three urban T-junctions, the same author concluded that overall TTC was more informative than PET about safety problems (in part because PET was not applicable to certain interactions) and that the Swedish conflict technique was the most useful overall measure of safety. He also concluded that it is more difficult to identify safety-critical events from video than to identify them from manual observation on-site. He suggests that an ideal video analysis methodology for identifying safety-critical events should include elements of both manual observation and video analysis:

> On-site observations are difficult to verify after-the-fact, whereas measures determined through a process involving video-analysis may be reviewed repeatedly and can be cross-verified by other analysts. Arguably, the analysis of two-dimensional video-imagery represents a poor substitute for on-site observation. The fact that observations are performed on-site allows the observer to carry out a more qualitative analysis, becoming aware of different site-specific safety problems such as: red-light violations, high flow rates, excessive vehicle speeds, large numbers of turning movements, pedestrians that cross at undesignated places or during red signal phases, and other situations that influence road-user behaviour and interaction negatively. This information can also be obtained using video-analysis, but is subject to limitations regarding quality and coverage. Arguably, the 'subjective' element of on-site conflict observation implies the application and acquisition of safety knowledge and experience in a qualitative approach to safety analysis that is often more informative and resource-effective that most other methods (page 220)

Thus video is useful for checking between-observer reliability and for confirming conflict severity. However, manual observers are better for highlighting safety problems and are able to overcome problems of video imaging.

Svensson (1998) suggests that there may be a need to refine the definition of the TA value in the Swedish conflict technique in order to arrive at an improved safety indicator. As stated above, the standard definition of TA takes the speed of only one road user, the one who takes evasive action, into consideration. Svensson suggests that the speed of the other party should also be considered and the higher of the two speeds used. This would result in an improved distinction between “safe” interaction with small time margins and “unsafe” interactions with small time margins. This suggestion was confirmed by Shbeeb (2000) who examined the implications of using the more severe of the two potential TA values when defining the seriousness of a conflict, i.e. choosing the road user with the higher speed as setting the conflict value. She found that this improved the validity of the Swedish TCT, particularly for signalised intersections.

© 2007 Highways Consultancy and Research Group

3. The Application of Conflict Studies to Rural Roads

The application of conflict studies to rural conditions is to our knowledge very limited. When reviewing the literature we came across two studies:

1. Studies at two rural intersections that form the basis for the definition of a serious conflict with a speed-dependent severity scale (Gårder, 1982)
2. A study with the aim of assessing an incident warning system on a two-lane rural road in Portugal (Svensson and Várhelyi, 1995)

As discussed in section 2.2, the original definition of a serious conflict was according to the Swedish Conflicts Technique "a situation when two road users are involved in a conflict situation where a collision would have occurred within 1.5 seconds if both road users involved had continued with unchanged speeds and directions". This definition of a serious conflict proved to work well at urban intersections with vehicles speeds around 50 km/h (30mph). As speeds at rural intersections are often higher, studies were carried out at two rural intersections to determine whether there was a need to change the threshold between serious and non-serious conflicts (Gårder, 1982). The mean speeds at these two rural intersections were 40 and 50mph. The studies showed that it was possible to carry out conflict studies at rural intersections but the definition of a serious conflict needed to be changed. The proposed new threshold was speed dependent and based on maximum braking plus a safety margin of 0.5 seconds.

On IP5, a two-lane major rural road in Northern Portugal, conflict studies were applied to assess the safety effect of an incident warning system (Svensson and Várhelyi, 1995). The incident warning system warned the drivers of slow-moving vehicles ahead and of oncoming traffic overtaking (i.e. approaching head-on in a vehicle's lane), by activating the flashing roadside poles. Video data was collected at two sites. To stage an incident a car was parked on the shoulder within the view of one of the cameras.

The aim of the study was to conduct safety evaluation of implemented systems. It was essential for the safety evaluation to perform quick and valid results from the trials, which in addition were on a small scale. The fact that Incident Warning Systems were new (i.e. there was no possibility to rely on previous knowledge about expected safety effects) and the prerequisite to obtain results shortly after the introduction made it essential to use other methods than accident data analysis. One of the methods chosen to assess safety was the Swedish Traffic Conflicts technique. The Swedish TCT is validated for urban conditions and with trained conflict observers recording the events at a site. Here the conditions were completely different, i.e. rural conditions, and there was no possibility for observers to be at site. The latter was due to difficulties in covering longer sections from the ground and in addition that it was impossible to secure their personal safety because of the high-speed traffic on the road. The solution was therefore to record the locations using video and to perform conflict observations from the video recordings. The normal procedure of training observers was extended with training from video. The video equipment was placed on bridges over the road, so that what was observed was in essence a convenience sample of the road length on which the system was operating. Thus this was a link-based study. It cannot be claimed that the conflict studies were performed strictly according to the Swedish TCT. Observations from video recordings were however in this case considered to be the second best solution. The criteria for selecting a "conflict-like" event was that it should have the character of being a serious conflict thus involving a collision course and evasive action and that the severity, based on TA / Conflicting speed, should fall into the category of serious conflicts. To further ensure satisfactory reliability, the same personnel and the same criteria were used for both the before and after study.

© 2007 Highways Consultancy and Research Group

The results of the assessment of the incident warning system implemented on IP5 in Portugal were the following: The most frequent conflict type in both the before and after studies involved a vehicle overtaking at a bad moment and thereby forcing the oncoming vehicle to take evasive action in order to avoid an accident. According to the conflict studies, and other parallel studies of number of overtakings and flows, there was no major change in safety between the before and after period on the IP5 road. In general, there was difficulty in reliably detecting conflicts: there were large numbers of potential conflicts which due to video resolution and foreshortening could not be defined with certainty as being serious conflicts. This indicates the difficulty of applying video capture for the analysis of conflicts on links, particularly where potential conflicts are scattered along a long stretch of road. In such situations manual observers will become bored through lack of activity and also may be a personal risk, while video data collection is problematic.

© 2007 Highways Consultancy and Research Group

4. Theoretical Issues

4.1 Surrogate safety measures

Both the U.S. Federal Highway Administration (FHWA) and the U.S. National Highway Traffic Safety Administration (NHTSA) are exploring the formulation and application of risk measures based on pre-crash or crash margin measures. A recent FHWA report is titled "Surrogate Safety Measures from Traffic Simulation Models" (Gettman and Head, 2003). The objective of this project is to derive surrogate measures of safety from existing traffic simulation models for intersections. Definitions of all possible conflict events and algorithms for calculating the surrogate measures are presented. Surrogate measures considered include time-to-collision, post encroachment time, deceleration rate, maximum speed, and speed differential. The report proposes that distributions and other statistics based on the surrogate measures can be used to evaluate the relative safety of alternative designs. Future work includes the development of validation methods to determine the value of surrogate safety analysis. This type of data collection presupposes a system based on automated video analysis which also is the context within which a future conflict technique should be analysed. However, there is currently no off-the-shelf automated system on the market. Even if there was, the "new" way of collecting serious conflicts would have to be proven and validated before being useful for safety studies. There would inevitably be a lengthy process of reviewing which surrogate measure or combination of measures was appropriate for which situation. For example:

- When is it appropriate to use TTC and when PET?
- Does required braking rate (also called required deceleration rate) better capture severity than either TTC or PET, as the results of Archer (2005) at urban and suburban intersections suggest?
- Should speed be considered differently, particularly for studying events on links?
- Should the minimum value of TTC (or PET) be used as opposed to the value at the moment that the evasive action starts?
- Should other derivatives of TTC be used, such as TET (time exposed to a TTC below a certain threshold) or TIT (time integrated TTC) as proposed by Minderhoud and Bovy (2001)?

4.2 The validated conflicts technique

Validity and reliability are two important issues strongly connected to the usefulness of a technique based on indirect safety indicators. Reliability, in our case regarding serious conflicts, answers the question if observers at site are able to distinguish serious conflicts from other events in traffic and if they are able to estimate the severity. The calibration study of Grayson et al. (1984) showed that observers detect 75% of the serious conflicts and are on average 0.05 seconds wrong when estimating the TA value and on average 3km/h wrong when estimating the conflicting speed. The conclusion is that once the serious conflict is detected it is also correctly scored. Validity answers the question to what extent the conflicts technique is able to describe the phenomena in traffic that it is intended to describe, i.e. the injury accident potential. Process validation studies show that serious conflicts can be used to describe the process preceding accidents, i.e. the evasive action patterns are similar and accidents represent a logical continuation of the serious conflicts on a severity scale. Product validation studies show that the conflict technique produces a valid estimate of the number of expected accidents with a satisfying variance. The validated conflicts technique is based on and takes into account::

- situations between two or more road users moving on collision course
- a human observer making observations at site
- intersections in urban areas
- observers' incompleteness in detecting serious conflicts and estimating the severity
- conflicting speed defined as the speed of the road user taking evasive action just before the evasive action starts
- observers' difficulties in estimating collision point for rear-end situations

© 2007 Highways Consultancy and Research Group

4.3 Implications for conflict studies at rural sites

In the context of performing Conflict Studies at rural sites it is important to recognize that the validated Swedish TCT does not involve:

- single vehicle accidents
- observations from video
- rural areas
- links
- relative speed of the involved road users

The suggestion is therefore to use a conflict technique that is based on the Swedish TCT but adapted to current circumstances, i.e. the conflict studies will not be performed strictly according to the Swedish TCT.

Single vehicle accidents are frequent events on rural roads. To get an understanding of this problem we suggest an analysis of events where vehicles are about to leave the lane and for instance measure the time-to-lane departure for these events. This could be done through a combination of manual and video techniques.

Rural areas: Studies (Gårder, 1982) show that it is possible to carry out conflict studies with human observers at rural intersections. It was in fact these studies that formed the basis for the new definition of a serious conflict with a speed-dependent severity scale.

Observations from video recordings: The studies cited above state that it is possible to use human observers at site to perform conflict studies as rural intersections. When performing conflict studies on a broader scale in rural areas and in more complex situations it might be advisable to use on-site observers for detecting the event and simultaneous video recordings to support the severity estimate i.e. to measure speeds and distances.

Links: It is not possible for human observers to cover any large distances. The choice of links should therefore be based on specific locations along the link where higher frequencies of safety related events can be expected, for instance merging sections or bends. When performing conflict studies at such sites, the on-site human observers should be supported by simultaneous video recordings.

Relative speed of the involved road users might better reflect the severity of the conflict than merely the speed of the road user taking evasive action just before the evasive action starts (Conflicting Speed, CS). This problem has earlier been noted in connection to estimating the severity of a conflict where pedestrians are involved and it is the pedestrian who takes evasive action. Due to low Conflicting Speeds these situations often end up as being non-serious conflicts even if the speed of the involved vehicle is high. If there had been a collision the injuries to the pedestrian would have been very severe which is not in correspondence with the severity of a non-serious conflict. Here, again, it is important to recognize that the Swedish TCT was developed and validated with the data collection techniques available at the time, i.e. human observers. The conflict technique and the coherent variables are therefore very much based on the capabilities of a human observer, which means that it is only feasible to identify TA or TTC at one moment in time. Now with automated video analysis within reach, the situation is of course completely different. In the near future, the ambition is to perform research into other safety indicators such as Relative Speed and values of TTC as they develop over time. In the meanwhile, for instance when there is support from simultaneous video recordings, it might be fruitful to identify Relative Speed in addition to Conflicting Speed especially when studies are performed at high-speed sites as occur in rural conditions. This would also avoid the problem that would arise if, for example, at a rural intersection the conflict is avoided by an action by the vehicle on the minor road, which is likely to be travelling relatively slowly. Accident prediction modelling for intersections on single-carriageway rural roads has shown that injury accident risk is related to main-road traffic speed to the fifth power (Taylor, Baruya and Kennedy, 2002).

Rear end conflicts – human observers are capable of detecting these events but have difficulties in estimating the severity, especially the distance to collision point i.e. the TA-value. Human observers at site together with simultaneous video recordings might be a good solution at sites where a high frequency of rear-end conflicts and accidents can be expected.

© 2007 Highways Consultancy and Research Group

5. Automated Video Analysis

5.1 Video recordings as a means to collect data

Video recording is a commonly used tool to collect data about road user behaviour. Compared to using road side observers it has many advantages; 1) it increases the possibility to make long-period observations 2) it increases the possibility to study locations that otherwise are "impossible" (too dangerous for the observer to be at the site, too large area for the observer to get a proper view, too low frequency of the events of interest, too complex road user movements) 3) less interference with the traffic process 4) possibility to look through the relevant situations over again 5) possibility to study very complex situations in detail 6) the observations can be split and transferred to time periods when staff is more available, etc.

5.2 Automated video recordings

With video recordings the task of the observer is moved from being an outdoors to an indoors activity. Thus, the disadvantages with a human observer as a detection unit still remain. An example: The most important deficiency of the Swedish Traffic Conflicts Technique is related to the reliability of the technique and more specifically to the fact that conflict observers sometimes fail to detect the serious conflicts. To move the detection of the serious conflicts from being performed by the observer at site to being performed from a video recording will probably not increase the detection rate significantly; the problem lies with the observer acting as a detection unit. To perform traffic observations from recordings is in addition at least as time consuming as making observations at site – it is often not possible to scroll through the recordings (depends of course on type of behaviour that is studied). Depending on type of behaviour to be studied, the accuracy in the estimates might also be reduced as the video recording can not provide the observer with a complete picture of the traffic environment.

The use of automated video analysis allows skipping the routine of watching through all hours of video recordings. The system selects the events of interest either by using algorithms that directly recognize the events or through describing the properties of the trajectories which then can be further analyzed by another set of algorithms. This implies that the observation periods can be extended considerably and much more data collected. This is especially valuable if the studied events are relatively rare. Such a system also opens up for the possibilities of studying road user behaviour at locations and at times of the day and year where it so far has not been cost effective to use human observers. It also makes it feasible to collect objective data about dynamic processes and that the data collection is performed in a systematic and, from one case to another, in an identical way.

The basic elements in an automated video analysis system are usually:

1. One digital camera mounted on a post or a nearby building. If there are multiple cameras these could either be synchronized so that the images can be merged or linked by timestamp so that they can be synchronized after the fact.
2. Calibration of the camera set up, to allow for transforming distances between the road-plane and the image i.e. to make it possible to measure positions, distances and speeds.
3. Detecting and tracking moving objects by applying foreground/background segmentation sometimes in addition using a feature-based tracking method.
4. The output is a dataset containing the movement for each object in the scene. Some systems also include algorithms for categorisation then the output also contains type of road user.

Then, of course, the degree of sophistication regarding the analysis and selection of events differ very much between different systems. There are many automated video analysis systems on the market. Most of them have a focus on monitoring car traffic and they are often applied on motorways to detect congestion and incidents (stops) or to measure speeds and flow. There is, however, a great market potential for more advanced applications capable of handling more complex situations including crossing manoeuvres and a mix of different types of road users i.e. urban conditions.

© 2007 Highways Consultancy and Research Group

5.3 Conflict studies and video recordings

In connection to conflict studies with the Swedish TCT the site is often video recorded. It provides the observer with a backup; makes it possible to once again look at some events in more detail. It also allows for other behaviour studies which are important complements to conflict studies like measuring the flow of different streams and types of road users and measuring speeds. In connection to the education of conflict observers the outdoor activities are always video recorded. Back in the classroom it is then possible to view and assess the conflicts again to give the observers correct feedback to their registrations. Until there is an automated video system that is able to select serious conflicts, simultaneous video recordings can assist the conflict observer at complicated sites. The selection of events is still made by the observer at site while the estimate of conflicting speed and position for evasive action can be verified afterwards from the video recordings. If the purpose of a study is to collect and analyse "conflict-like" situations the registrations can of course be performed directly from video without prior selection at site. In such case it is, however, very important to keep in mind that such events are not in line with the validated definition of a serious conflict; a validation that is based on registrations made by observers at site.

5.4 Automated video analysis

The new U.S. Strategic Highway Research Program (SHRP) II has identified the need, as accident numbers decline, to use surrogates of accidents to gain an improved understanding of factors affecting accidents and injuries by studying the interrelationship between driver behaviour, traffic conditions, geometrical design and safety. The program plan points out that the relatively low number of and random variation in accidents call for the use of more frequent events such as conflicts, critical incidents and near-accidents, etc. Collision margin measures such as time-to-lane departure or time-to-accident will be assessed. Today advanced technology enables data collection of the entire traffic safety process including the pre-collision and collision phase. An important aspect is that the data collection now can be based on objective measures of behaviours. SHRP II is planning a large in-vehicle data collection, using video and other metrics collected with an in-vehicle data recorder to study driving in "natural" circumstances, i.e. as it occurs in normal driving. Incidents and the factors that increase risk and cause those incidents will be analysed in detail. A parallel site-based data investigation is also planned. The site-based data collection will use multiple overhead video cameras to record the motions and relative positions of vehicles, focussing on intersections. The site-based system will build on the System for Assessment of the Vehicle Motion Environment "SAVME" (Ervin et al., 2001) which is a portable semi-automatic system, using cameras pointing down into an intersection to detect and reconstruct vehicle trajectories and hence longitudinal and lateral motion (speed, accelerations, yaw movements). The data on movement patterns will be used to define and validate new traffic safety indicators i.e. surrogate measures of accidents. In the program it is however emphasized that this type of extensive data collection will require a system based on fully automated video processes and analysis. A project aimed at developing and designing a site-based video system was approved in 2006. The system will be a portable automated video system that provides exposure-based, surrogate measures of accident risk. As an additional part of this project, a field study will be conducted to demonstrate the relationship between the surrogate measures and actual accident frequencies. The task is to improve the capabilities of existing systems. The full site-based data collection is planned to start in 2009.

Saunier et al. (2003) report on a French project with the aim to study how different strategies in signal settings affect safety. Road users and their vehicles are called *mobile*. The approach is based on zones in the intersection and that mobiles must pass the conflict zone at one time or another. Among the interactions in the conflict zone the authors singled out the following *categories of interactions*:

- *downstream category*: interactions with collision course between a mobile or a group of mobiles entering the conflict zone and a mobile or group of mobiles stopped in the conflict zone,
- *stationary cross traffic category*: interactions between a mobile or a group of mobiles in the conflict zone and a mobile or groups of mobiles stopped in the cross traffic storing zone,
- *moving cross traffic category*: interactions with a collision course between a mobile or group of mobiles entering the conflict zone and a mobile or group of mobiles moving in the cross traffic zones

Eight cameras covering a complex signalised intersection. The information from the eight cameras is then processed by a system developed at the French National Institution of Transport and Safety

© 2007 Highways Consultancy and Research Group

Research (INRETS) which produces the spatial occupation of the intersection; zones that are empty; zones where mobiles are moving and zones where the mobiles are stationary. To get the dynamics this information is then combined to get detection patterns. The basic unit is groups of mobiles. The detection is therefore the detection of groups of mobiles and interactions refer to interactions between groups of mobiles. The determination of whether there is an interaction or not between groups of mobiles is based on the information about presence and movement in different zones and the presumption about mobiles following the correct direction of traffic flow. From this information about the groups of mobiles it is possible to get approximate estimates of distances between protagonists and their speeds. The authors "define two indicators, standing for the severity information contained in data,

- the *extrapolated proximity*, defined as the minimal extrapolated distance between the protagonists,
- the *speed differential* between the protagonists, defined as the length of the difference of their speed-vectors at the time of detection"

The intention was not to apply the Traffic Conflicts Technique in an automatic detection devise but to systematically detect categories of interactions (according to the categories above).

A modular system was developed to:

1. Detect the interactions that belong to the predefined categories of interactions; based on a pattern recognition method.
2. Estimate the two severity indicators i.e. the extrapolated proximity and speed difference. The extrapolated proximity can be directly computed while an artificial neural network, supervised learning, first has to "learn" the indicator speed difference before it can be calculated.

The results from tests of the second module with artificial neural network are encouraging.

As a reader it is hard to understand the automatic detection part as it is referred to as a system developed at INRETS. Even if it was not the intention of this work to perform an automated conflict study, the system shows potential of detecting categories of events and estimate the minimal extrapolated distances and speed differences between interacting vehicles. These may be supplementary indicators to e.g. TTC, TA/Speed, well suited for future definitions of conflicts when the data collection is based on automated video recordings instead of human observers at site. As a consequence of any new proposal of a new safety indicator, this new indicator of course has to go through the procedure of validation. This validation shows whether this indicator describes the phenomena that it is intended to describe i.e. injuries in traffic.

The American System for Assessment of the Vehicle Motion Environment "SAVME" that was reported in (Ervin et al., 2001) is a portable semi-automatic system. Video data is collected from multiple cameras mounted above the section; data is processed and a track file is produced for each vehicle. The track file contains the vehicle trajectory i.e. time stamped X-Y positions. This is, in a later process, expanded to derive "inter-vehicular" variables of range, range-rate and azimuth angles that positions the individual vehicle in relation to all other vehicles present at the site. The track file data were validated against data from instrumented vehicles passing the test site.

Since 2001 the system has been further developed by the American National Highway Traffic Safety Administration (NHSTA) at the Vehicle Research and Testing Center. Overall, the system is capable of providing accurate information on the movement and relative position of every vehicle passing through the roadway segment. When fully developed, it is believed that this system has the potential to provide a semi-automated and objective way to record accidents, near-accidents and traffic conflicts. (SAVME is by other reports referred to as a semi-automatic system. The SAVME report itself does unfortunately not reveal the inner parts of the system which makes it impossible to form an opinion about the level of automation of the system.)

Laureshyn and Ardö (2006) present an automated video analysis system as a tool to study road user behaviour. The development of this automated video analysis system is a collaborative work by traffic safety researchers and computer vision researchers at Lund University in Sweden. The prevailing system is based on video recordings from one camera that is mounted at a nearby building. The data is stored and processed later by background/foreground segmentation and spatial correlation algorithms, providing the description of the detected road users' trajectories. A predetermined set of criteria forms a filter, which selects the events or situations of interest. These cases are further analyzed, depending on the particular purpose of the study, while the results are compared to or

© 2007 Highways Consultancy and Research Group

validated against other types of measurements or just by visual control. The current system is capable of detecting, tracking and describing the movement of larger vehicles like cars and buses with satisfying accuracy. Within a year the system will also be able to include pedestrians and cyclists.

Description of the system: The first task is to detect the objects i.e. the road users. This is done by applying foreground/background segmentation which is a classical solution for detecting and tracking objects in a video sequence. To obtain the trajectories, adjacent foreground pixels are clustered into objects and objects overlapping between adjacent frames are clustered together into tracks. Before being able to make measurements the images are rectified which means the original images are transformed into images appearing as if they were produced by a camera looking straight down at the intersection. Now the distances can be measured from the image in pixels and transformed into meters by simple scaling. The accuracy in estimating the position of the objects is however still not satisfying. This can be solved in different ways; 1) to form 3-dimensional models that fit the shape of the object. As the number of models grow the task to choose the correct model for each object becomes difficult. Pedestrians and cyclists may demand dynamic models as their shapes change continuously; 2) to use stereo vision i.e. two synchronized cameras that cover the same area but from different angles. However, the cameras need to be mounted quite far from each other and the whole construction becomes bulky and less mobile; 3) two or more separate cameras overlooking the site but mounted at different parts. The cameras are not synchronized but as the images still can be time-stamped it is possible to produce two (or more) image streams that are somewhat synchronized. The synchronisation is not good enough to perform classical stereo vision but the images from the different cameras can be used to track road users that are occluded in some angles, either by each other or by static objects. The above problem regarding accuracy in estimating position has much less impact on the estimate of speed i.e. the speed estimates have high accuracy. The aim is to store information about each detected road user in a database as a trajectory. Each trajectory will contain a dataset describing the road user properties (e.g. type, size, direction of travel), a sequence of positions, direction of travel, speed and acceleration values during the time the road user was within the camera view. The trajectories can then be further clustered into events, which are the main unit of information stored in the database. Depending on the purpose of the study different types of events can be defined, e.g. a passage of a single road user, an encounter between two or more road users or all the passages during a certain period of time. Tools are being developed for calculating parameters like travel time, gap size, delay, Time-to-Collision, Post-Encroachment-Time, distance from the road user to some control point or other road users. It will also be possible to aggregate and analyse speed and gap distributions, speed profiles and trajectories.

Parkhurst (2006) presents a project where a digital video analysis system was developed, implemented and tested at intersections. Driver behaviour was measured at urban and rural non-signalised intersections. The objective was to develop a portable video recording station with the capacity to perform one week of continuous recording. A 250 gigabyte hard drive was used and power was secured by using four high-capacity deep-cycle marine batteries. A standard camera-intersection configuration was adopted which defines the exact location of the camera i.e. a configuration that is the same for all set-ups. Then the set-up is calibrated i.e. to allow for transforming distances between the road-plane and the image. To detect and track the moving objects a frame by frame extraction of objects in the scene is used. Each frame is compared with a frame that does not contain any moving objects i.e. vehicles. Then objects are linked between frames to create trajectories for each object. The trajectory then reveals the identity of the object i.e. if it's a car or pedestrian. The output is a dataset containing position, velocity, size and identity for each object in the scene. The main advantage of this system is that it is simple; a single camera and a simple calibration process. Another advantage is that comparably large amount of data can be collected to a low expense. There are, however, also a number of disadvantages; 1) Not all objects are detected 2) Not possible to track all objects between images 3) The identification of an object into car or pedestrian is not perfect 4) Limited to analyses of a single lane. The author finalized by concluding that a multiple camera system probably would detect and track objects more reliably. On the other hand would the advantages in the simplicity also be lost; additional calibration and more time consuming analyses.

Messeldoni et al. (2004) and (2005) present a system, SCOCA, which is able to automatically detect vehicles, determine category of vehicle, estimate speed and to track the trajectories. When the cameras are installed the system is provided with camera height, view angle and camera intrinsic parameters to allow for an auto-configuration of the specific site. The core of the video analysis

© 2007 Highways Consultancy and Research Group

system comprises two main modules working in parallel i.e. the *Detector and Tracker* and the *Object Parameter Extractor*. The *Detector and Tracker* detects objects by using background subtraction paradigm i.e. compares each frame with a reference frame which does not contain any moving objects and thereby extracts moving objects. The system works with an algorithm, based on a Kalman filtering method, to deal with problems caused by high variability of the lightning conditions. The tracking follows two strategies; one is the mentioned moving object detection method and the second is a much faster feature-based tracking method. A few small windows, characterized by edges, are selected to track the object. These features are then searched for in the subsequent frame within a sphere of expected positions, estimated from the previous known displacement. The output of the *Detector and Tracker* is list of objects with data about their movement in the image. The *Object Parameter Extractor* makes a classification of the object and analysis its path through the image in particular determining entering and exiting lanes and speed. The categorisation works in two steps: a model-based and a feature based classification. The former compares the shape of the object with predefined shapes of known objects in a database and chooses the one that looks most alike. This method is particular useful when the site coverage is not very wide. It also turns out to be the method that produces the best matches and it enables reliable computation of the real trajectory and speed. The feature-based classification refines the first step by extracting some visual features from the object to assign the object into the correct classification category. In the latter report this system is used to estimate accident risks based the probability of a collision and a qualification of the damage. The probability of a collision is based on indicators like Time-To-Collision (TTC), Post-Encroachment-Time (PET) and Time-Headway (TH). The severity of the accident is based on type of road users involved as vulnerability differ between road users.

Molinier et al (2005) present a study with the aim to develop methods for detecting and tracking vehicles. The camera was mounted in a helicopter which ensured video recordings from straight above i.e. the problem of occlusion did not exist. There are on the other hand other and more specific problems to deal with when using a moving camera. The first step was therefore to compensate for the camera motion and to register the video to a GIS map. The moving objects were then detected by using adaptive background subtraction i.e. each frame is compared with a reference frame which does not contain any moving objects and thereby is it possible to extract the moving objects. As there always was traffic in the scene a vehicle free image had to be created. So once a background image was available it was subtracted to the current image, forming a difference image. Some of the areas declared to be in motion were in fact illumination changes not modelled in the background update. These false detections had to be discarded before tracking the vehicles. Vehicles were identified and tracked with a tracker based on spatiotemporal connected components analysis. Without the problematic occlusion the 3D-connected components analysis should allow vehicle tracking without risking that two vehicles are tracked as a single moving blob. To estimate the speed, the centroids of the vehicles were extracted and the change in position was measures in an interval of 12 frames. A very encouraging result of the study was that if the vehicles were correctly detected they were also successfully tracked.

5.5 Video analysis

Andersson (2000) and (2002) presents a system where the video recoding gets time stamped and the camera position is calibrated i.e. a transformance between road and image coordinates to allow for estimates of distances and speeds. The positions of the road users are collected manually by an operator. The data collection is manual but the analyses are automated.

There is an increasingly use of CCTV cameras in urban areas, for traffic management purposes and for security surveillance. Conche and Tight (2006) show on the potential of using existing set-up of CCTV cameras for detailed analysis of accidents. The paper also points at the possibility to extend the coverage by additional strategically placed cameras. The accidents are manually selected from the video recordings.

© 2007 Highways Consultancy and Research Group

6 Accident Data and Procedures Preliminary Review

6.1 Accident Data

Within the Inception Report the main sources of accident data were identified as the STATS19 database and the On-the-spot (OTS) accident database. The OTS database is restricted to South Nottinghamshire and therefore the initial interrogation of STATS19 information was limited to the same area that the OTS project operates to identify clusters of accidents where records were available in both data sets (in Rushcliffe, Gedling, Broxtowe and part of Nottingham City).

The Trunk Roads within this area of South Nottinghamshire include parts of the M1, A52, A453 and A46. The data from STATS19 was collected for the 5 years between 01/11/2001 and 31/10/2006.

A total of 1469 accidents were recorded. Table 1 shows the split of those accidents along each route:

ROUTE	Length of Route, miles	Year 1 (01/11/01 – 31/10/02)	Year 2 (01/11/02 – 31/10/03)	Year 3 (01/11/03 – 31/10/04)	Year 4 (01/11/04 – 31/10/05)	Year 5 (01/11/05 – 31/10/06)
M1	4.0	17	13	20	16	18
A52	31.5	151	152	166	176	150
A453	7.8	21	26	24	21	19
A46	28.0	114	109	87	85	84

TABLE 1: Collisions between 01/11/2001 and 30/10/2006 (by route).

From the accidents collected by OTS since 1997 to date, a total of 222 have been recorded on the Trunk Road Network. The study has matched those sites where there is information from both STATS19 and OTS databases.

It is identified that **3** sites are common in both databases; these are

1. A453 just prior to Ratcliffe Power Station (Grid Reference 449952 329322),
2. A52 Sherwin Roundabout (Grid Reference 450448 337937), and
3. A52 Saxondale Roundabout (Grid Reference 468712 339609).

Work is proceeding to plot OTS and STATS 19 accident locations on an OS base to identify common cluster sites that could be considered for inclusion in the Conflict Study.

6.2 Discusssions with Area 7 MAC

Discussions have been held with AMScott (Area 7 MAC) to confirm their programme of accident remedial work. AMScott are programming works along the A52 corridor (between Gamston and Barrowby) for the next financial year, with the A46 to be treated the following year. An additional site along the A1 is proposed to be treated in the next financial year.

The preliminary list of sites is shown in Annex 1. This method has revealed 12 additional potential sites to be discussed during the forthcoming workshop:

A453 Junction of Green Lane with Barton Lane.
A52 Junction with Wollaton Road
A52 Junction with Thoresby Road
A46 Margidunum roundabout to Saxondale roundabout (Link)
A46 Stragglethorpe Crossroads
A46 Colston Gate
A46 Kinoulton Crossroads
A46 Owthorpe Crossroads
A46 South slip roads, Widmerpool grade separated junction
A46 Newark Bypass (79 – 81)
A46 Junction with Hawton Lane
A46 Junction with Elston Lane
A46 Junction with Lodge Lane

© 2007 Highways Consultancy and Research Group

7 Conclusions

7.1 Past use of Conflict Studies

It can be argued that observations of conflicts is at least as good as accident data for the before and after evaluation of remedial measures at sites. However, it is important to determine that there is no major contribution to the crashes at the site from single-vehicle accidents, such as 'run-off-the-road' accidents, or any specific issue with night time accidents being different from daytime accidents. Conflict studies cannot, as at present defined, be used to investigate single-vehicle crashes. With that proviso, it can even be argued that conflict studies are superior to accident studies in that the immediate precursors to the event can be reliably determined rather than reconstructed post hoc. They are also arguably superior for the determination of safety problems at a site, in partly because of their larger numbers but also because, information is captured covering the approach of the parties involved.

However, at present there exists no fully validated technique for conflict studies at rural intersections and still less one that can be readily applied on rural links. In order to gain full value of adapting the existing techniques, the rural situation must be carefully considered to ensure that the validated conflict to accident correlations are maintained. Thus, the current investigation aims to address the rural situation through appropriate adaptation of existing practice, rather than developing a new technique which would not be validated. It should be noted that this approach may limit the scope of the technique in the rural situation, such as applicability to links. However, establishing such a validated conflict study for rural roads will provide a firm platform for future developments that may address rural links, such as developing an automated image processing system that could reliably replace the human observer.

What is proposed instead is to use a commonsense approach which is informed by both practical and theoretical considerations. This approach will:

- Identify conflict situations using manual observers
- Use video analysis as a tool for checking the reliability of the manual observers and for providing data on vehicle speed and path
- For intersection purposes, define the conflict severity on the basis of the more severe of the two Time to Accident (TA) values as proposed by Shbeeb (2000)
- For links, define the conflict severity on the basis of the relative speed of the participants

From the experience obtained in the evaluation of the incident warning system on the Portuguese high-speed road IP5 (Svensson and Várhelyi, 1995), it can be concluded that there are severe difficulties in applying conflict studies to evaluating the safety performance of rural links in situations where the conflicts are likely to be distributed randomly along the length of the link. It is therefore suggested that it is more sensible to consider only those situations where there is a drastic reduction in road quality within a link. Such a situation might occur, for example, where there is a change for dual carriageway to single carriageway, or where there is a lane drop such as at the end of a 2+1 section.

7.2 Identification of Accident Data

Potentially, there appear to be sufficient collision sites within the South Nottinghamshire area to enable the study to proceed. Task 3 will proceed with the refinement of the above list and preparation will be made for the forthcoming workshop to be held on the 23rd May 2007.

Further discussions will take place with HA/AMScott to enable sites with specific improvement schemes already identified to be incorporated into the study so that "before and after data" can be obtained.

© 2007 Highways Consultancy and Research Group

8 References

Amundsen, F. and Hydén, C. (1977). Proceedings of first workshop on traffic conflicts. Institute of Transport Economics, Oslo.

Andersson, J. (2000). A new traffic analysis method based on image processing. Bulletin 193, Department of Technology and Society, Lund University, Sweden.

Andersson, J. (2002). Image processing for analysis of road user behaviour: a trajectory-based solution. Bulletin 212, Department of Technology and Society, Lund University, Sweden

Archer, J. (2005). Indicators for traffic safety assessment and prediction and their application in micro-simulation modelling: a study of urban and suburban intersections. Doctoral dissertation, Department of Infrastructure, KTH Royal Institute of Technology, Stockholm.

Conche, F. and Tight, M. (2006). Use of CCTV to determine road accident factors in urban areas. Accident Analysis and Prevention, 38:1197–1207

Ervin, R., MacAdam, C., Walker, J., Bogard, S., Hagan, M., Vayda, A. and Anderson, E. (2000). System for Assessment of the Vehicle motion Environment (SAVME). Final Report Volume I. Report UMTRI-2000-21-1, University of Michigan Transportation Research Institute, Ann Arbor, Michigan USA.

Ervin, R., MacAdam, C., Vayda, A. and Anderson, E., (2001). Applying the SAVME database of inter-vehicle kinematics to explore the natural driving environment. TRB Paper No. 01-0496.

Gårder P. (1982). Konfliktstudier i landsvägskorsningar (Conflict studies at rural intersections) [In Swedish with a summary in English]. Department of Traffic Engineering and Planning, Lund University, Sweden.

Gettman, D. and Head, L. (2003), Surrogate safety measures from traffic simulation models. Report No FHWA-RD-03-050, U.S. Department of Transportation, Washington, D.C.

Grayson, G.B., Hydén, C., Kraay, J.H., Muhlrad, N. and Oppe, S. (1984). The Malmö study: a calibration of traffic conflict techniques. Report R-84-12. Institute for Road Safety Research SWOV, Leidschendam, The Netherlands

Hauer, E. (1978). Traffic conflicts surveys: some design considerations. TRRL SR 352.

Hauer, E. and Gårder, P. (1986). Research into the validity of the traffic conflicts technique. Accident Analysis and Prevention, 18(6):471-481.

Hydén, C. (1987). The development of a method for safety evaluation: the Swedish traffic conflicts technique. Bulletin 70, Department of Traffic Planning and Engineering, University of Lund, Sweden.

Latham, E. (2004). Know the road: conflict analysis as a tool to predict accidents. MSc thesis, Institute for Transport Studies, University of Leeds.

Laureshyn, A. and Ardö H. (2006). Automated video analysis as a tool for studying road user behaviour. Proceedings of 13th ITS World Congress, London, 8-12 October.

Lord, D. (1996). Analysis of pedestrian conflicts with left-turning traffic. Transportation Research Record 1538.

Messelodi, S., Modena, C.M. and Zanin M. (2004). A computer vision system for the detection and classification of vehicles at urban road intersections. ITC-irst Technical Report T04-02-07, ITC-irst, Povo, Trento, Italy.

© 2007 Highways Consultancy and Research Group

Messelodi, S. and Modena, C.M. (2005). A computer vision system for traffic accident risk measurement: a case study. ITC-irst Technical Report T05-06-07, ITC-irst, Povo, Trento, Italy.

Migletz, D.J. , Glauz, W.D. and Bauer, K.M. (1985). Relationships between traffic conflicts and accidents. Report No. FHWA/RD-84-042, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Minderhoud, M.M. and Bovy, P.H.L. (2001). Extended time-to-collision measures for road traffic safety assessment. Accident Analysis and Prevention, 33:89-97.

Molinier, M., Häme, T. and Ahola, H. (2005). 3D-connected components analysis for traffic monitoring in image sequences acquired from a helicopter. Image Analysis: 14th Scandinavian Conference, SCIA 2005. Joensuu, Finland, 19-22 June.

Muhlrad, N. (1993). Traffic conflict techniques and other forms of behavioural analysis: application to safety diagnoses. Proceedings of 6th ICTCT Workshop, Salzburg.

Older, S.J. and Spicer, B.R. (1976). Traffic conflicts: a development in accident research. Human Factors 18(4): 335-350.

Parkhurst, D. (2006). Using digital video analysis to monitor driver behavior at intersections. CTRE Iowa State University, USA.

Perkins, S.R. and Harris, J.L. (1967). Criteria for traffic conflict characteristics. Report GMF 632. General Motors Corporation, Warren, Michigan.

Perkins, S.R. and Harris, J.L. (1968). Traffic conflict characteristics: accident potential at intersections. Highway Research Record, 225: 35-43.

Saunier, N., Midenet, S. and Grumbach, A., (2003). Automatic detection of mobile interactions in a signalized intersection. Proceedings of the 16th ICTCT Workshop, Soesterberg, The Netherlands.

Shbeeb, L. (2000). Development of a traffic conflicts technique for different environments. Bulletin 188. Department of Technology and Society, Lund University..

Spicer, B.R. (1973). A study of traffic conflicts at six intersections. LR551. Transport and Road Research Laboratory, Crowthhorne.

Strategic Highway Research Program (SHRP) II, (2006). Revised safety research plan: making a significant improvement in highway safety: Transportation Research Board, Washington, D.C.

Svensson, Å. (1998). A method for analysing the traffic process in a safety perspective. Bulletin 166, Department of Traffic Planning and Engineering, University of Lund.

Svensson, Å. and Várhelyi, A. (1995). Conflict studies for safety evaluation of an incident warning system. Deliverable 23 of HOPES project; DRIVE II Project V2002.

Taylor, M.C., Baruya, A. and Kennedy, J.V. (2002). The relationship between speed and accidents on rural single-carriageway roads. TRL Report 511. TRL Limited, Crowthorne.

Transport and Road Research Laboratory (1987). Guidelines for the traffic conflict technique. Institution of Highways and Transportation, London.

Williams, M.J. (1981). Validity of the traffic conflicts technique. Accident Analysis and Prevention, 13:133-145.

© 2007 Highways Consultancy and Research Group