INDIRECT MEASUREMENT OF SAFETY -
THE "CONFLICT METHOD"

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Part I. The Logic of the Conflict Method and its Implications

1. We are concerned here with the measurement of safety in transport. Let us agree at the outset that safety (or the lack thereof) is measured by the expected number and severity of accidents occurring during a specified period of time(1).

2. Inferences about the magnitude of the expected accident rate may be made directly on the basis of accidents recorded in the past. This if often inadequate in more ways than one(2). In recent years, indirect methods for the estimation of the expected accident rate have gained popularity. In an attempt to avoid the need to rely on accident records, inferences about safety are made indirectly from the occurrence of near misses or "conflicts".

3. There is no smoke without fire. Applied to transport safety, it is anticipated that a high rate of conflict occurrence will be associated with a large accident rate and vice versa.

This is the intuitive foundation on which researchers and practitioners begun to develop the conflicts techniques. The concept of a "conflict" is intuitive but vague. It is hardly surprising therefore, that most researchers adopted slightly different definitions of what a conflict is. There are those who identify a conflict with "evasive action", others who detect its occurrence as a function of the proximity in time of the colliding elements. Of course, many shades, nuances and variations exist between the methods used, in dependence on the severity of an evasive action which is deemed decisive or the proximity of elements on collision course which is

Numbers in parentheses refer to notes commencing on Page chosen to distinguish conflicts and normal situations.

4. Diversity of approach during the initial stages of the development of a novel technique is desirable. It holds the promise of convergence on the most satisfactory procedure. However, continued fragmentation of effort and persistent difference in the underlying concept of the term "conflict" will be debilitating. As will be demonstrated in the sequel, the usefulness of the conflict method hinges on the transferability of research results over relatively large geographical areas. Failure to converge on a common definition of what constitutes a conflict will effectively preclude the wide practical application of the conflict technique of safety measurement. It appears therefore, that after several years of exploring various alternatives, concensus should be sought on the fundamental question: how should conflicts be defined?

5. It is tempting to launch the discussion with the question: "What is a conflict?". This start leads to a blind alley. The term "conflict" derives its usefulness (if any) from the facilitation of indirect estimation of the expected accident rate. If so, it should be defined to best perform this task. Thus, the term "conflict" is subject to definition and not deduction from observation.

6. Experience accumulated so far indicates that some definitions of "conflict" have been more successful in predicting accidents than others. Thus the fundamental question may be further specified to read: how should the term conflict be defined so as to maximise the predictive power of the conflict method of safety measurement.

The fundamental question would be incomplete if it was not tempered by the requirement of practicability. Whatever the definition of the term conflict which is eventually adopted, it must be characterized by one outstanding feature. That is, estimation of the rate at which conflicts occur must be practicable. Whether the estimate of the conflict rate is obtained by field observation, calculation on the back of an envelope or computer simulation, it has to be done at a reasonable cost and during a relatively short period of time.

7. In spite of the uncertain trumpet which those familiar with the conflicts technique sound, it is being applied to an ever larger set of circumstances: vehicular traffic at junctions, protected pedestrian crossings, comprehensive traffic management schemes, design of road networks in residential areas, airspace utilization, marine navigation etc.

It is unlikely that a simple and brief definition of the term "conflict" will be sufficiently specific to provide clear cut guidance in all situations. A useful definition of conflict between aircraft over the North Atlantic is probably different from the definition of conflict to be applied to pedestrian safety at pelican crossings. In consequence, it is best to organize the discussion below into two parts. In the first, the principles guiding the definition of the term "conflict" will be listed and clarified. These principles are common to all situations to which the conflict method may be applied. They should facilitate informed choice of the definition to be used in each specific situation. In the second part, the application of these principles to selected situations is illustrated.

8. Let us begin the quest for a reasonable definition of the term

"conflict" by illustrating in a simplified manner how indirect measurement of safety might be accomplished using the conflicts method. I can think of only two somewhat different circumstances. In the first the task would be to estimate the magnitude of the expected accident rate for a system. For want of a better term this task will be termed "absolute safety measurement". Consider e.g., a specific junction. Observe the occurrence of conflicts at the junction for a specified period of time. Let it be known that one accident occurs on the average, say, in 10,000 conflicts. Divide the conflict count by 10,000 to obtain the estimate of the expected accident rate for the period of observation. Note, that the accident-to-conflict ratio (1 in 10,000) must be known from other sources and can not be derived from the conflict count itself.

The second type of situation in which the conflicts method might be used is probably more prevalent and possibly less demanding in terms of information from external sources. It involves only measurement of the ratio of expected accident rates, not of their magnitude. This will be called "relative safety measurement". Consider the same junction as before. A change, say, in the duration of the amber phase of the signal is being contemplated. A conflict count is carried out before and after the change. If the definition of conflict is adequate, the ratio of the two conflict rates derived from field counts is an estimate of the ratio of expected accident rates before and after the change, as required.

9. It may be helpful to describe at this point an accident occurrence sequence which seems to be implied by the manner in which the conflicts method as described above is to be applied. The

sequence consists of two steps. Firstly, a potentially dangerous situation develops. It will be called a "conflict". A fixed fraction of these conflicts is converted into accidents.

In terms of probability,

E(Accidents/Unit of time) = E(Conflicts/Unit of time) x P(Accident| Conflict).

Or equivalently,

Expected Accident Rate = (Expected Conflict Rate) x (Accident-to-Conflict Ratio). ... 1

The sequence of accident occurrence implied by the procedure for indirect safety measurement and captured by equation 1 is schematically depicted in figure 1.

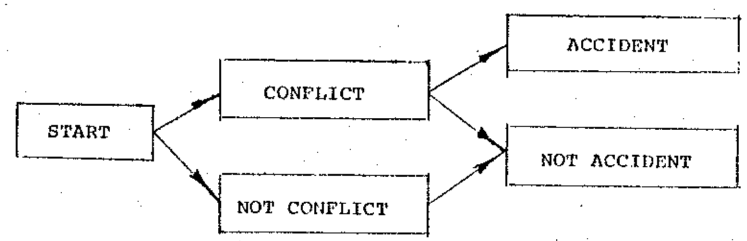

Figure 1

The boxes stand for events and the arrows determine their chronological ordering. In this diagram, the only path to the "accident" event is via the "conflict" event. Following a "conflict", either an "accident" or a "not accident" event materializes. The "accident event" follows the "conflict" event with a probability which equals the accident-to-conflict ratio. Equation 1 conforms to this process.

10. The scheme in figure 1 requires that

the conflict event be defined such that all accidents be preceded by conflicts.

This seems to be at variance with the bulk of present practice. It is customary at present to identify conflict occurrence by the observation of some evasive action by drivers. However, not all accidents are in fact preceded by observable evasive action. In some cases no evasive action at all takes place; in others it is not observable. From the scanty evidence there is, it may not be even the majority of accidents which are preceded by observable evasion.

Thus, either insistence on the requirement of conflict precedence is not really necessary, or the "evasive action" based conflict definitions are faulty. The issue needs examination.

Assume for a while that an "evasive action" based conflict definition has been adopted. Thus, accidents may occur without being preceded by a conflict. If so, the equality in equation 1 does not hold any more. To restore its validity one needs to add to the right hand side an estimate of the expected number of accidents occurring without being preceded by a conflict. The only practical way of doing so is to assume that there exists a constant ratio between the expected number of accidents which are preceded by conflicts and those which are not. Also, that this universal constant holds for all circumstances. This is what users of the "evasive action" based conflict definitions have been assuming (implicitly).

Founding a new method of safety measurement on such as assumption is not too appealing. Its validity is of course debatable.

However, in the absence of a convincing way to demonstrate correctness or falsity debate is unlikely to be fruitful. The only constructive step possible is to illustrate circumstances in which reliance on such a heroic assumption is likely to lead to failure.

Assume that a conflict is counted whenever a vehicle brakes at a rate in excess of 0.3g. Accidents will occur not only when such evasive action was unsuccessful but also in a variety of other circumstances. When drivers do not recognize danger in time; when their brakes fail; if pavement friction factor is less than 0.3g etc. In all these circumstances a conflict (as defined) does not precede the accidents. On the basis of this illustration can one reasonably expect a constant ratio to exist between accidents preceded by conflicts and those which are not? For, if one compares two sites differing only in, say, their pavement friction, that with the lower friction factor is likely to have a higher proportion of accidents not preceded by a conflict. Paradoxically, the more hazardous site will tend to have less conflicts, as the pavement can not sustain decelerations in excess of 0.3g.

This paradox is a general one and illuminates yet another deficiency of the "evasive action" based conflict definition. Evasive action is a sign of the occurrence of a dangerous situation. It is, however, also a sign that it has been properly recognized as such and that evasive action was possible. It is precisely the breakdown of communication between the driver and his environment as well as the unforgiving road system not allowing evasive action to be taken, which constitutes a significant part of the safety problem. Thus, absence of evasive action may be as revealing of hazard as its presence. More will be said about the inadequacy of evasive-action based conflict definition in note 8.

In summary, it seems prudent to require that the conflict definition be so selected that all accidents are preceded by conflicts. In particular, the use of evasive action for conflict definition may lead to serious problems.

11. When the expected accident rates of a system "before" and "after" treatment are compared, or when the comparison is between the expected accident rates of two different systems, we speak of relative safety measurement.

With reference to equation 1, the ratio of expected conflict rates in this case is an unbiased estimate of the ratio of expected accident rates, provided that the probability accident-given-conflict is the same in the two situations which are being compared.

It follows, that only those conflict definitions are legitimate (useful) for which the probability of an accident to ensue once a conflict has occurred is the same in all situations which are being compared.(3)

12. In most situations knowledge of relative safety is insufficient.(4) For absolute safety measurement (estimation of the magnitude of the expected accident rate) knowledge of two values is necessary (see equation 1). Estimates of the expected rate of conflict occurrence may be obtained from field surveys, models, etc. But where are the needed estimates of the accident-to-conflict ratio to come from? These must come from special purpose studies. Studies, in which conflicts are counted on systems for which also estimates of the expected accident rate are available. The accident-to-conflict

ratio is then estimated by dividing the accident and conflict rates. And here is the rub. For us to use the estimate of the A/C ratio derived from somebody else's study,

(a) We must use in our conflict study the same definition of the term conflict as has been used for the estimation of the A/C ratio,

(b) We must make sure that "our conflict" is very much like "their conflict" insofar as the likelihood of conversion into accident goes.

In other words, the "situations which are being compared" encompass the systems the safety of which is being measured and all those which were used for the estimation of the A/C ratio. For, suppose that our definition of conflict was to differ from that used for estimation of the A/C ratio. Surely there is no reason to expect the same probability of accident-given-conflict to apply.

Similarly, even if the same conflict definition is used, but some local characteristics render the likelihood of conversion of conflicts into accidents different from the A/C ratio derived elsewhere, its use would yield erroneous measures of safety.(5)

13. Having argued that statements (a) and (b) must be complied with if we wish to have a useful method for the indirect measurement of safety, let us explore the implications of such compliance of the definition of the term "conflict".

To estimate the magnitude of the expected accident rate, we count conflicts. The estimate of the conflict rate is then multiplied by the applicable accident-to-conflict ratio. This "applicable accident-to-conflict ratio" must be gleaned from some external source.

where from? With some imagination and optimism one can hope for a state of affairs in which the measurement of safety using the conflict method is widespread. (Obligatory? Standard practice?). Through research and experience a catalogue of A/C ratios has been compiled. Each entry specifies the best current estimate of the A/C ratio applicable in a specific situation. (One entry may read, e.g., ...vehicles trapped by amber light when opposing traffic is moving: A/C ratio = 1/12,300). Possibly estimates of accuracies are also listed. Subsequent editions of the catalogue will have finer conflict categories and more accurate estimates.

Two conclusions follow. First, unless the user of the conflict method adopts the catalogue conflict definition he has nothing to go on. He can count conflicts till doomsday without being able to estimate safety. Failure to work in strict accordance with the catalogue definition of "conflict" yields an estimate of "conflict rate" which has no known relationship with "safety" as defined in the first paragraph. It follows that the imaginary "catalogue" will be a unifying device forcing all users to adopt the same conflict definition.

It is somewhat surprising to realize that the basic function of a common catalogue and common conflict definition has not been explicitly stated in the literature on the conflict method, nor has its absence been missed. I can think of three reasons. One, that my perception of the use of the conflict method is in error. Two, that users of the conflict method intend to apply it only to the task of relative safety measurement, Three, that activitity in this

field has been predominantly research orientated and concerned in the main with discovering an operationally successful conflict definition, relegating other tasks till some later time.

The second conclusion indeed applies to research. Its central task seems to be the generation of a useful "catalogue"(6). That is, the conduct of special purpose studies the objective of which is the estimation of A/C ratios for various situations. Since estimates of satisfactory quality will ensue from the conduct of several studies, it is mandatory that:

a. Researchers agree upon and adopt the principles which govern the selection of conflict definitions.

b. Researchers agree upon and adopt a single definition of the conflict event for each specific situation.

Failure to do so will tend to perpetuate the present fragmentation, yield estimates of A/C ratios which are of insufficient accuracy, prevent widespread application of the conflict method and possibly cause its unwarranted demise.

14. The implications of statement (a) from section 12 have been explored above. We will now use statement (b) of section 12 to delineate closer which are legitimate definitions of the conflict event and which are not.

Two facets of the A/C ratio need to be remembered. First, what it is an estimate of the probability "accident-given-conflict". Second, that to use an A/C ratio, it needs to be copied from a "catalogue". It follows, that the use of an A/C ratio so obtained and its application to a specific case is justified only if there is good reason to believe that the probability of an accident to ensue from a conflict in the case under consideration is the same as in the situations which led to the catalogue value. This is what statement (b) means. It also imposes certain obligations on the conflict definition. For, if as a result of poor choice of definition, the probability "accident-given-conflict" will continue to depend on factors which are specific to each site, the catalogue value is of no use.

To illustrate, consider again the "trapped-by-amber" conflict. Suppose that only one A/C ratio is catalogued. In consequence this value will be used where rain and ice are rare as well as at junctions which are frequently slippery. The implication of such use is that definition of the conflict event has been found such, that the probability of an accident to follow a conflict does not depend on the state of the pavement. Can such a definition be found?

If not, one could obviously insert into the catalogue two A/C ratios. One for dry pavement conditions, the other for slippery conditions.

It appears that the definition of the conflict event must be so chosen that the probability of "accident-given-conflict" depend significantly only on factors which are common to all situations to which the A/C ratio will be applied.

Conversely, a definition of the conflict event so chosen, that the probability of "accident-given-conflict" is likely to depend significantly on factors specific to each location and not common to all situations to which the A/C ratio is to be applied, is not a legitimate one.

The underlined statements are effective guidance in the search

for an adequate definition of the conflict event. They also lead to several questions. The first is at the very heart of the conflict method. This method, so it seems, relies on a hypothetical feature of the event chain which leads to accidents. Namely, that beyond a certain point of this chain of events, the outcome (accident or not) depends only on a small number of factors common to many sites. Is this in fact so?

The second question is more practical. By selecting the definition of the conflict event very "close" to the accident event one hopes that the same A/C ratio will apply to many situations. This however also means that conflict occurrence is rare and their count is difficult. To circumvent this difficulty one could choose a conflict definition farther removed from the accident event. This would render conflicts easier to count. However, the A/C ratio in this case is likely to depend on a larger number of factors. This means many more entries into the catalogue, each entry applicable to a smaller set of conditions. Which choice is best advised?

15. The hypothetical feature of the event chain implicit in the underlined statement of the preceding paragraph needs further discussion.

Visualize, say, a red vehicle approaching an intersection. At some early point in time its probability of being involved in an accident while passing through the intersection is affected by the general flow of traffic, the type of control (stop signs, signal etc.) the intersection layout etc. At some later point in time, say after the vehicle's entry into the intersection, the probability of its being involved in an accident no more depends on the general flow of traffic. It depends now on the specific constellation of the vehicles in the vicinity, their respective speeds, the drivers who control them, the prevailing pavement condition, the level of illumination etc. Thus, while some of the "average" local factors cease to exert influence over the probability of accident involvement, some "instantaneous" local factors take their place. Let us follow the vehicle for a few more seconds and imagine that it got into rather close proximity to another vehicle. What happens beyond this point depends predominantly on the two drivers involved, the capabilities of their vehicles and possibly the friction provided by the pavement. Factors such as weather, visibility, signs, layout etc. may not be of any importance at this point in time as far as the probability of accident occurrence is concerned. If so, one should be able to define conflicts to be such that the A/C ratio would apply to all situations in which driver, vehicle and pavement characteristics can be assumed to be on the same average.

To generalize the red vehicle story, imagine a sequence of events which precede collisions and each of which could be chosen to serve as our definition of conflict. In the schematic event chain shown in figure 2, nodes 1, 2, 3... depict such events.

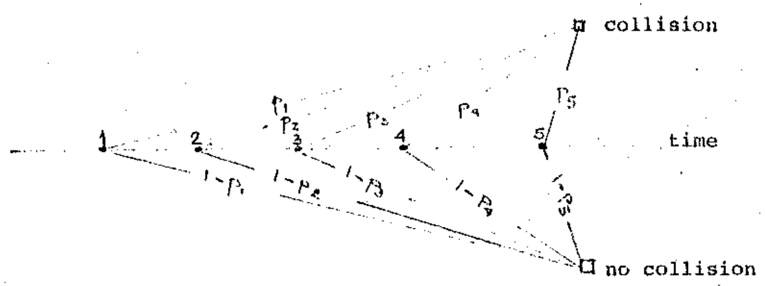

Figure 2. Event Chain

Let p_1, p_2, ... denote the probabilities that a collision will ensue once events 1, 2 ... have occurred. For events far removed in time from the potential collisions (say, event 1) the probability (p_1) surely depends only on the average site conditions which are forecast some time into the future. For events much closer in time to the potential collision (say, event 3), the probability (p_3) depends on a fairly specific set of conditions characterizing the site at that time. For events even closer than that to the potential collision it is hypothesied that the probability of collision ceases to depend on a host of site specific conditions and is influenced only by some fairly general traits having to do with what people can and can not do, what vehicles are capable of etc.

One can believe or disbelieve the red vehicle story. Added speculation will not bring us any closer to establishing its validity. The notion that a conflict definition exists such that the probability of an accident ensuing depends only on few almost universal factors is quite appealing. Appeal, however, does not assure validity. The way to find out is to define conflicts as best we can and then test whether the assumption was warranted. (This, to be sure, is not a very sound procedure. For, should one find that a certain conflict definition yields A/C ratios which are sufficiently stable over a number of sites, one would tend to accept the hypothesis. Should, however, the A/C ratios vary from site to site, one would put the blame on an inadequate conflict definition and continue to search for a better one).

16. The second question raised in paragraph 3 relates to the

choice between alternative conflict definitions (events 1,2....5 in figure 2).

Let us review the considerations which should affect the choice. We hypothesized in the previous section that the "closer" to the collision the conflict event is selected, the fewer local factors influence the value of the A/C ratio. Choice of a conflict definition "close" to collision would therefore mean that only few A/C ratios need to be catalogued. Thereby, investment in research aimed at the estimation of A/C ratios will not be exorbitant. Accident data needed for such studies should be easy to come by and the accuracy of estimated A/C ratios should be adequate. The drawback of choosing such a conflict definition is in the fact that events very close to collision tend to be rare. This may render the conduct of conflict counts impractical in terms of cost and duration.

Choosing a conflict definition which is farther removed from collision will increase the number of factors which determine the value of the A/C ratio. If so, for each value of a factor, an A/C ratio needs to be provided in the catalogue. This, of course, magnifies the amount of research needed. Very soon, one comes against an objective obstacle - lack of sufficient accident data.

Let us try to estimate, e.g., the A/C ratio for (1) vehicle-vehicle collision; (2) of the rear-end type; (3) at junctions; (4) at night; (5) when the pavement skid number is 3-4. We will have to count conflicts and obtain accident information in with these five factors. As the pavement skid number prevailing

at the time of the accident is not ordinarily recorded, estimation of the A/C ratio categorized by skid number is probably not feasible. (At most one may attempt to provide A/C ratios for such categories as appear on the accident report form, i.e., dry, wet, icy).

While the complexity of the catalogue is increased by choosing a conflict definition farther removed from the collision, the frequency with which such events occur is now increased. This, in turn, may render the task of counting conflicts cheap and fast.

It appears then, that the range of choice (of a conflict definition) is delimited from the right (figure 2) by the frequency of conflict occurrence which is acceptable for field counts. It is delimited on the left by the number of factors and categories for which good estimates of the A/C ratio can be provided.

17. In sections 3 to 16, the substantive nature of the conflicts method for indirect safety measurement has been discussed. It prescribes certain rules to be followed when attempting to define the conflict event. The main features of the conflict method and the rules for conflict definition are summarized below:

I. The aim of the conflict method is to obtain estimates of the expected accident rate using the equation:

Expected Accident Rate = Expected Conflict Rate x Accident to Conflict Ratio. The estimate of the expected conflict rate is usually obtained from a site survey.

The estimate of the Accident to Conflict Ratio will be copied from a "catalogue". The catalogue will give best available estimates of the A/C ratio. It should be created by a co-ordinated research effort.

II. To facilitate estimation the conflict rate, the conflict event needs to be defined. The definition must be chosen to facilitate sufficiently accurate estimation of the expected conflict rate and to allow the conduct of surveys. The conflict definition must obey the following two rules:

A. The conflict event must precede all accident events.

B. The conflict event must be so chosen that the probability "accident-given-conflict" be the same in all systems the safety of which is compared or to which a certain A/C ratio is applied.

III. The "conflict method" can not be used for estimation of expected accident rates without a "catalogue" of A/C ratios being available. It is the task of researchers

A. to agree upon a single conflict definition to apply to each specific situation.

B. to obtain estimates of A/C ratios and their accuracy and compile those in a catalogue.

Part II. Application

18. Part I of this paper was devoted to the examination of the principles which should guide the definition of the conflict event. The purpose of Part II is to apply these principles to specific cases in order to see whether a practical procedure for the selection of a conflict definition emerges.

19. Consider, e.g., accidents between main road and minor road vehicles occurring when minor road vehicles enter the junction without realizing its presence beforehand(7).

For this type of accident, first a conflict definition will be suggested, applicable to the "before" and "after" relative safety comparison at the same site. Next, still in the realm of relative safety measurement, a conflict definition will be devised to be used in the comparison of relative safety at different sites. Following this, a conflict definition for absolute safety measurement will be considered.

20. The task then is to measure the relative change in the frequency of the aforementioned type of accident which is brought about by a treatment modifying the behaviour of minor road vehicles. Assume that the treatment (oversize signs, lane separation island, etc.) does not affect the behaviour of the main road vehicles. If so, the following tentative conflict definition might be satisfactory:

A conflict is said to occur when a minor road vehicle enters the main road without realizing its presence beforehand.

This definition complies with two requirements. First, for an accident of the type examined to occur, a minor road vehicle must enter the main road without realizing its presence beforehand. Thus all accidents are preceded by conflicts as defined. Second, in the two situations compared, the main road traffic has not changed. Thus, once a minor road vehicle entered the junction "unaware", the chance of an accident occurring is the same "before" and "after". Consequently,

$$\frac{E(\text{Accident rate before})}{E(\text{Accident rate after})} = \frac{E(\text{Conflict rate before})}{E(\text{Conflict rate after})} \quad \ldots(2)$$

21. However, direct observation of conflicts using the tentative definition in paragraph 20 is impractical. Such conflicts are simply

too rare. Even at a bad spot one should not expect more than, say, two such conflicts to occur per month. One could attempt to estimate indirectly the rate at which the (tentatively defined) conflicts occur. Consider, e.g., measuring the distance from the stop line at which vehicles begin decelerating. Such information may be plotted in the form of a cumulative frequency distribution as in figure 3. A vehicle entering the junction without realizing its presence beforehand does not decelerate till D=0. Thus, the intercept of the extrapolated cumulative distribution with the vertical axis is an estimate of the proportion of vehicles in "conflict" (provided that it is possible to weed out vehicles which did not decelerate but entered sufficiently slowly to be aware of the main road and its traffic).

22. To obtain in this case an estimate of the rate at which the tentatively defined conflicts occur, one needs to extrapolate the tail of the cumulative distribution. Three points deserve noting. First, the specific type of measurement from which figure 3 was plotted is not the only or the best method. Better results may be obtained from measurement of other one-dimensional variables (e.g. time-to-stop-line) or possibly multi-dimensional distributions (distance, speed, deceleration etc.). Second, for the purpose of extrapolation, the right hand part of the distribution is largely irrelevant. This concurs with the current practice of selecting a threshold value for conflict events. Events to the right of the threshold do not count as "conflicts". Thirdly, for extrapolation, the shape of the curve to the left of the selected threshold is needed. This requirement is at variance with present

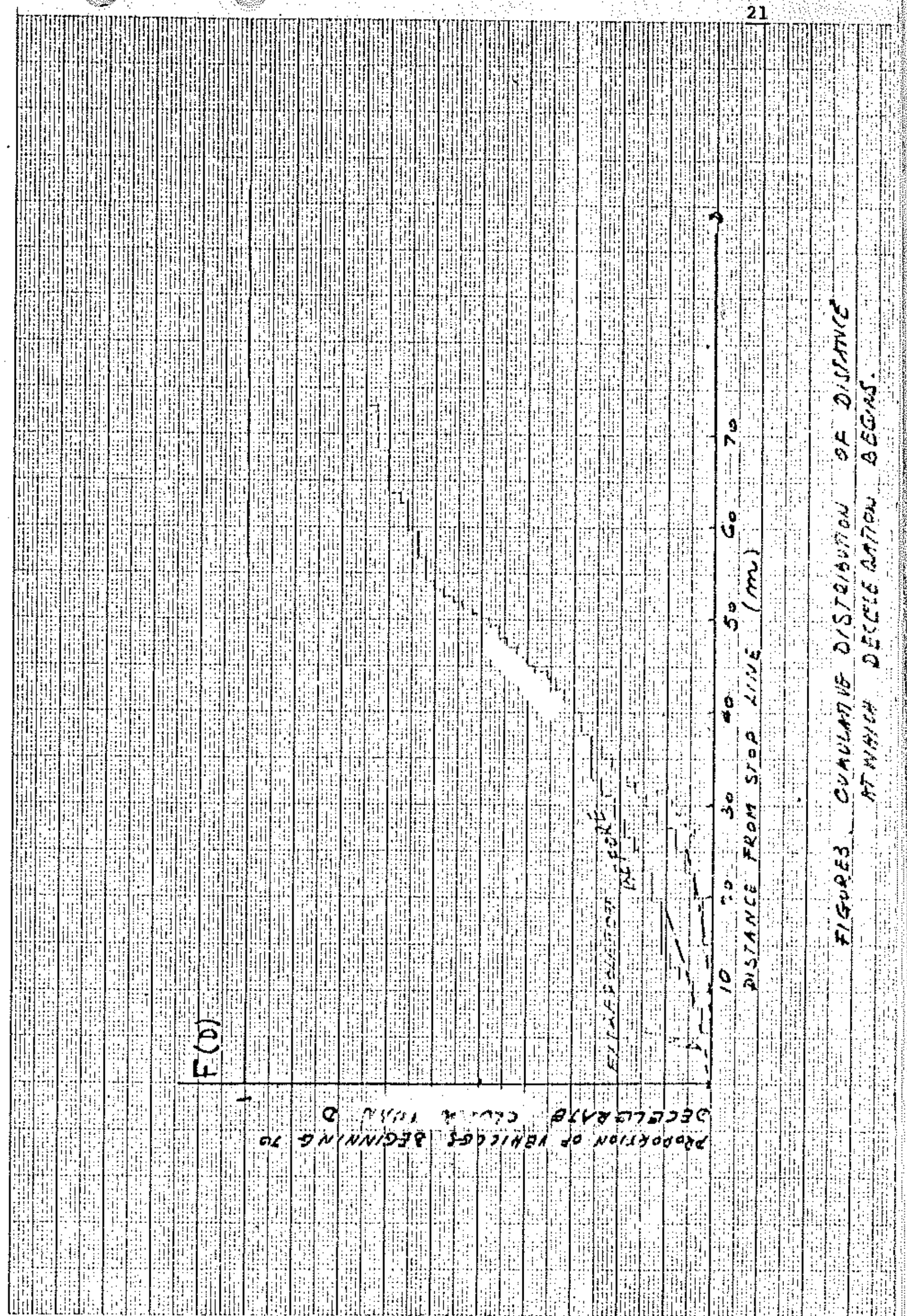

FIGURE 3 CUMULATIVE DISTRIBUTION OF DISTANCE AT WHICH DECELERATION BEGINS.

practice in conflict studies. At present, the result of a conflict survey is a single point on the curve.

23. It may be possible to alter the conflict definition which has been adopted tentatively (par. 20) to render observations more practical and to increase correspondence with present practice.

For the time being, we wish merely to estimate the ratio of the expected conflict rate before and after treatment. (Equation 2). This is given by the ratio of the intercepts with the vertical axis of the extrapolated cumulative distributions (figure 3). The ratio of the cumulative distribution ($F_{after}(D)/F_{before}(D)$) plotted as a function of D is shown in figure 4. On the extreme right, the ratio is unity as the effect of the treatment is not felt beyond a certain distance from the junction. On the vertical axis, the value of the ratio is the estimate of the relative change in accident rate (of the type defined in paragraph 19) due to the treatment. If the curve joining the two extremes is of the form shown in figure 4, it is easy to revise the tentative definition of the conflict event. The ratio of the cumulative distributions at D^* is seen to be the same as at D=0. Therefore, the probability accident-given-"vehicle-decelerates-after-D^*" is the same before and after treatment. Thus, the definition may be revised to state

> a conflict is said to occur if a minor road vehicle does not begin decelerating till past a distance D^* before the stop line.

Should this newly defined conflict event be sufficiently frequent, estimates of the rate of which conflicts occur can be obtained from observation. Also, the conflict event is now more akin to the presently used evasive-action-based definitions. A subtle

difference, however, needs to be noted. For the above defined conflict evasive action (deceleration) need not occur at all. Even vehicles which enter the junction without realizing its presence beforehand "do not begin decelerating till past D^*", and therefore count as conflicts.[8]

24. It is the task of research to examine the function $F_{after}(D)/F_{before}(D)$. Should one find consistently a horizontal segment near the vertical axis, the conflict event may be defined as suggested in paragraph 23. Any other regularity might facilitate extrapolation of the relationship to D=0. A word of caution is in order. Adoption of a threshold D^* without first establishing the shape of the curve in figure 4 may lead to error. If, in figure 4, e.g. D^* is selected to be 30 m, one would impute a 5% increase in accidents to a treatment which in fact reduced the rate by some 20%.

25. Discussion so far revolved around the measurement of safety at the same site "before" and "after" treatment. The conflict definitions suggested for use in this case will not work when safety at two different sites is to be compared.

Investigating safety "before" and "after" at the same site, conflicts were defined solely in terms of events occurring to the minor road vehicle. Implicit was the assumption that the "treatment" (which distinguishes "before" from "after") did not affect the flow or behaviour on the major road.

When two different sites are to be compared, conflicts can no more be defined in terms of events occurring to minor road vehicles only. For one, major road traffic flow may be different at the two sites. Thus, even if "unaware" minor road vehicles were to

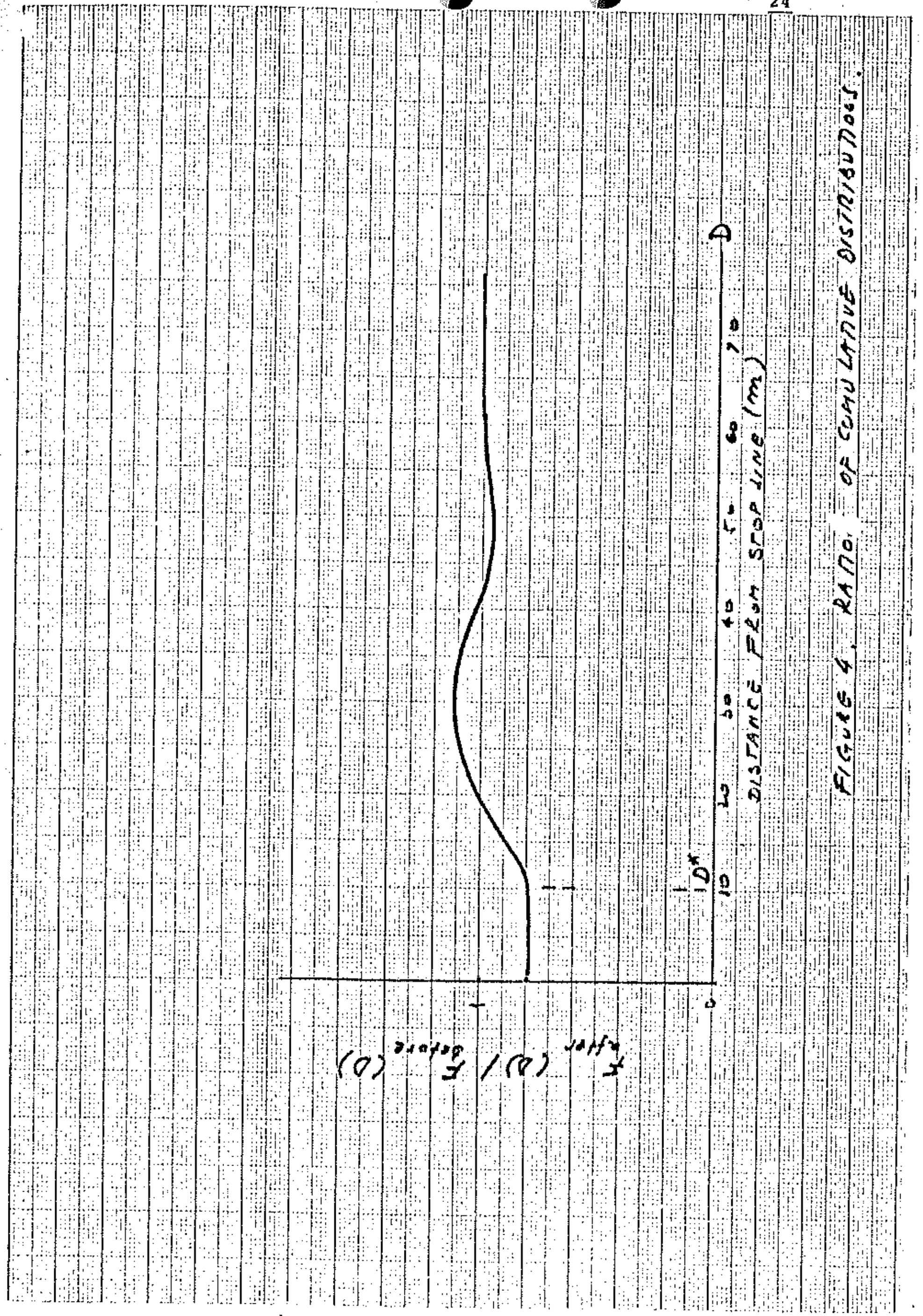

FIGURE 4. RATIO OF CUMULATIVE DISTRIBUTIONS

emerge with equal frequency at both sites, their chance of colliding with major road vehicles might be different. For two, the physical setting of the two sites (e.g. sight distances) may have important repercussions on the way major road vehicles behave when confronted with the imminent emergence of an "unaware" minor road vehicle.

To meaningfully compare the safety at two sites, it is essential (as always) that the P(accident/conflict) be the same at both. A definition of the conflict event needs to be devised for this to hold. This new definition must be such that differences in major road vehicle behaviour and flow are reflected in the rate at which conflicts occur.

Before attempting to devise a conflict definition suited for comparison between different sites, clarification of the kinematics involved may be helpful.

26. We are considering collisions between "unaware" minor road vehicles and vehicles on the main road. A collision can occur only if the main road vehicle is in the "conflict region" (0,X) where

$$X=VT-\tfrac{1}{2}AT^2$$

with

X	distance from front of main road vehicle to near side of minor road vehicle trajectory	m
V	speed of main road vehicle	m/sec.
A	constant deceleration of main road vehicle	m/sec.^{2}
T	time spent by minor road vehicle in path of main road vehicle	sec.

It seems (figure 5) that the conflict region depends only weakly on the deceleration of the main road vehicle. Change of direction

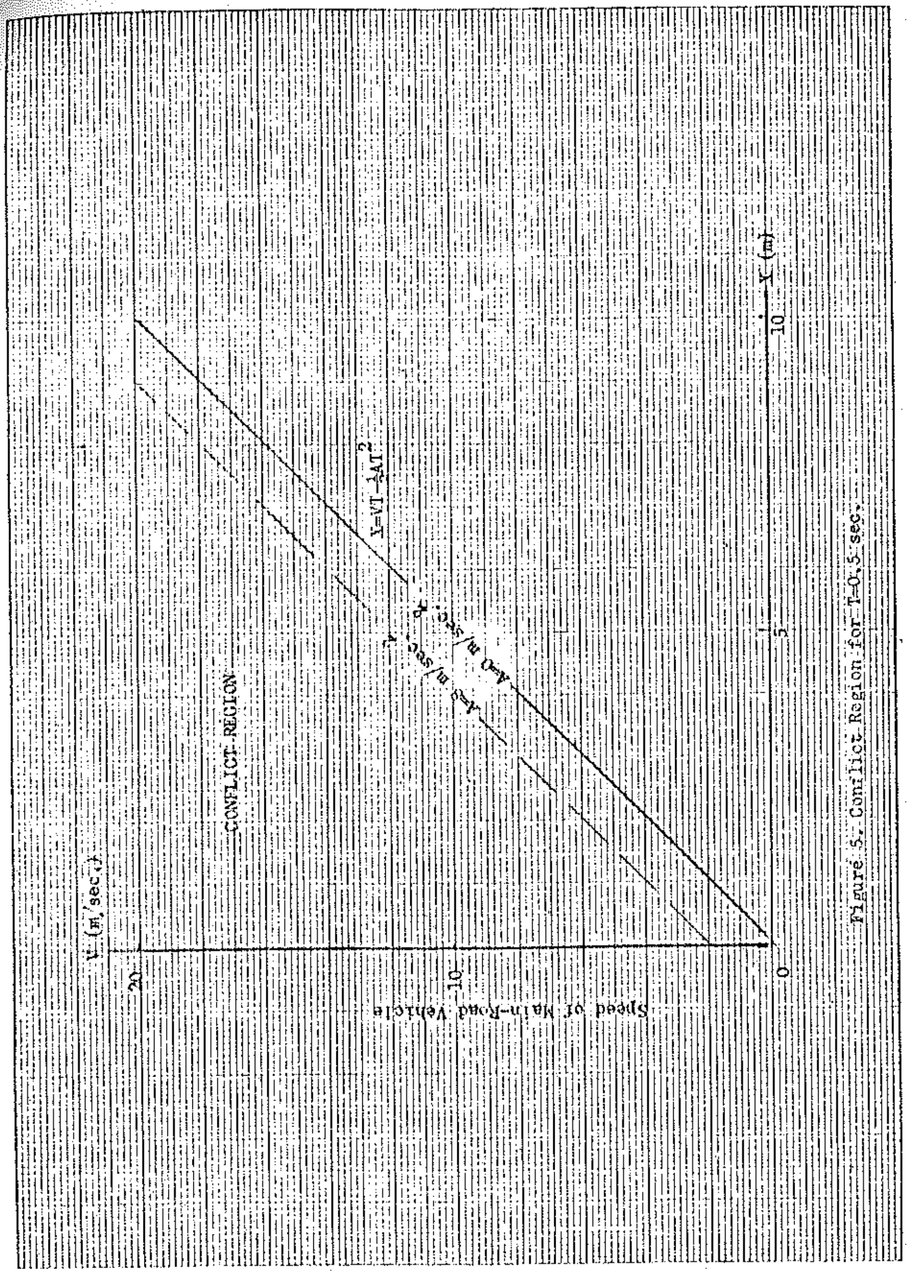

Figure 5. Conflict Region for T=0.5 sec.

might be a more successful evasion. One may speculate, that if a minor road vehicle emerges "unaware" and a main road vehicle is in the conflict region, the occurrence of an accident is a matter of chance which depends only of the abilities of drivers and vehicles and therefore remains the same at all sites.

If such speculation is warranted, a tentative conflict definition follows: It is the event when a minor road vehicle enters the main road "unaware" and a main road vehicle is in the conflict region.

This definition satisfies two requirements. All accidents (of this type) are preceded by conflicts (as defined). The probability accident-given-conflict is the same for the systems compared.

The problem now is one of estimating the rate at which such conflicts occur.

27. The task of conflict rate estimation is relatively simple if it is sensible to assume that the behaviour of major road vehicles is unaffected by the actions of "unaware" minor road vehicles. This may be so because the minor road is hidden from view or because such is the general mode of behaviour on main roads.

In this case, estimation of the conflict rate requries

a) Measurement of minor road vehicle behaviour and extrapolation such as suggested in paragraph 21 to estimate the rate at which "unaware" vehicles emerge from the minor road.

b) Measurement of the distributions of V, and T and flow on the major road to find the probability of a major road vehicle to be in the conflict region when an unaware minor road vehicle crosses its path.

In the special case when the distributions of V and T are the same at both sites, estimation is as in the "before" and "after" case except that the right hand side of equation 2 needs to be multiplied by the ratio of main road flows.

28. To assume that the behaviour of major road vehicles is not affected by what is happening on the minor road may not be warranted in many cases. One might speculate, that when sight distance is adequate, some main road vehicles may take precaution not to be in the conflict region if a minor road vehicle approaches the junction with no apparent intention to stop. In principle, this behaviour is subject to measurement and modelling. It is the task of research to provide the tools whereby measured behaviour at the site can be translated (extrapolated) into the rate at which main road vehicles are in the conflict region. (Much like the extrapolation of "conflict rate" from data in figure 3.)(9)

29. Often knowledge of relative safety is insufficient. Real treatments usually affect several types of accidents. Consider, e.g., installation of a separation island on the minor road to alert drivers to the presence of the main road. While collisions to "unaware" vehicles may be reduced, collisions with the island itself will increase. To form an opinion on the effect of a treatment, usually changes in absolute numbers of accidents need to be known.

Conceptually, it is a minor step from relative safety measurement at different sites to absolute safety measurement. The only additional piece of information needed is the value of the applicable probability "accident-given-conflict". Also conceptually, estimates of this value are easy to obtain. All it takes is to measure

conflicts and count accidents at many sites to obtain statistically reliable estimates. This is the task of research. In practical terms, it is a costly and arduous task, the product of which is a catalogue of accident-to-conflict ratios.

The only point of principle to raise here, relates to the domain over which one must maintain the same definition of the conflict event. The cornerstone of the conflict method is the insistence that the probability of an accident to ensue once a conflict has occurred must be the same for all systems the safety of which is being compared. When safety is to be measured in absolute terms, one is implicitly comparing the system under scrutiny with those systems from the examination of which the catalogue values of the accident-to-conflict ratio have been obtained. Thus, the conflict definition must be such that all these systems to which the catalogue value will be applied have the same probability "accident-given-conflict".

NOTES:

(1) I chose to distinguish between the expected and the actual number of accidents during the specific period of time. This is a rather important distinction. Legitimate difference of opinion may exist about the very concept of expected number of accidents and therefore explicit justification is in order.

The stated aim is to describe an important property of the transport system or parts thereof - the property of safety. Safety is just a general term. We mean specifically that property of the transport system which manifests itself in the occurrence of accidents.

Unlike length, mass etc. which are fairly definite and permanent properties of certain systems, accident occurrence is characterized by irregularity and "randomness'. One is hardly surprised if six accidents occur at a junction one year and none during the next without there being any significant change in traffic, weather, geometry, etc.

What then is a permanent property of a system (say junction) which may be useful in characterizing safety? One needs to resort, so it seems, to concepts such as "average", "frequency in the long run", "expected" etc. None of these concepts is without difficulty as they involve imagining an impossible situation. Imagine then a junction and count the number of accidents during the current year. Repeat the "current year" (impossible isn't it?) and count again. Repetition means, that the same traffic flows obtain, but not the exact replication of each movement, that vehicles are from the same population but not the identical vehicles pass again through the junction etc. Hypothetical repetition of such imaginary counts of yearly accidents would yield an average value which approaches a stable number as the number of counts increases. This is what is meant by the term "expected annual number of accidents".

I have now created a double headed monster which reveals only its unimportant head - the actual number of accidents. The important head (the "expected value") remains forever shrouded in mystery. Yet I am arguing that the mysterious "expected value" is the real measure of safety - the only guidance for action. This may offend common sense, as reality (the actual accident) is deposed in favour of an entity the existence of which is merely postulated. It follows,

that some substantial reasons for the choice must be given.

The first reason has been alluded to earlier. Namely, that the actual number of accidents is essentially unpredictable in the same sense as is the outcome of a roll of a die. What we would regard as the same transport system, can have widely different accident experience in two equivalent time periods. A measure of safety which can assume different values for identical systems is not very useful.

Having resigned ourselves to the fact that the actual number of accidents is practically unpredictable, we can proceed to the next reason for favouring the expected value. The best we can do, so it seems, is to state that the actual number of accidents will be X with probability Y. To do so, we need an estimate of the expected value-at least.

The third reason for "expected" and against "actual" is derived from the use to which a measure of safety is normally put. Such measures are used to judge improvement or deterioration; effectiveness or its absence; cost and benefit. All of these, so it turns out, are measured by the expected number of accidents (possibly classified by severity).

Finally, this is what practitioners have been trying to do anyway. An attempt is made always to diagnose safety on the basis of accident records averaged over a number of years. An average of this sort is used in order to characterize the intrinsic property of the system under consideration. It is an estimate of the "expected number of accidents". The practice of averaging may not have been stated explicitly as an attempt to estimate the expected accident rate, but I feel that it was meant that way.

If so, why create a strawman? Why argue at length for the acceptance of the notion that it is the expected number of accidents that counts if it is standard practice already? For two reasons. Firstly, because some are reluctant to concede on ideological grounds that the aim of measurement in transport safety is the estimation of expected accident rates. It does not do any harm to make the argument explicit. Secondly, because failure to distinguish between actual and expected accident rates leads to unnecessary confusion. Notably it leads to the unfounded expectation that an accident prediction method (such as the conflicts technique) should predict the actual number of accidents. This is as unrealistic as it is to aim at predicting the outcome of a throw of a die. The most we can say is that it will be on the average 3.5., and this is all that matters.

I have argued that if there is a property of the transport system characterizing its safety, it is measured by expected values. Specifically, a change in the level of safety is a change in the expected number and/or severity of accidents. This in turn means that every inquiry about the level of safety and its change must answer the question: what is the expected number and/or severity of accidents and the change therein? The estimation of expected accident rates is then the central problem of safety management and research.

(2) The shortcomings of relying on accident records of the past for the estimation of expected accident rates are many.

Firstly, there is the moral objection. Before anything can

be said about the safety of a transport system component (a junction, a vehicle design, a signal timing) a number of accidents must occur. The practice of experimenting with the lives, limbs and property of people seems to be the exclusive right of the military and of transportation engineers.

Secondly, accumulation of a sufficient number of accidents takes time. In the interim many changes occur in the system under scrutiny. As the system changes, so does the expected accident rate. Thus, reliance on records of the past can not yield estimates which are either current or accurate.

Thirdly, the need to wait for a long time before sufficient data is available for evaluation has important "institutional" repercussions. The management of safety is the outcome of public opinion, political responsiveness and initiative and of action by institutions of agencies executing safety programs. A period of data collection which is measured in years exceeds by far the attention span of the public, the term of office of a politician and often the average tenure in the same job of the civil servant. Thus, the effectiveness of safety action seldom gets evaluated simply because by the time the information is available, nobody is interested in it any more. Other problems occupy the public, the politician lost his seat and the engineer has retired or has been promoted and is responsible for entirely different activities.

It is the net result of the third shortcoming which may exert the most profound influence on safety management. Management of safety is expensive. Think of the resources devoted to the enforcement and adjudication of the traffic law; the time and money spent on driver education, vehicle licensing and inspection, roadway lighting, publicity campaigns etc. etc. Very little is known about the effect on safety of most safety management programs. It is not because these are untried. It is because program evaluation spanning a period of several years is often institutionally impractical. Progress toward rational action in safety management is hampered by the absence of adequate tools for the measurement of safety. Indirect methods of safety measurement may remove this obstacle to progress.

3. It may be useful to consider at this juncture the difference between the concepts of "exposure" and "conflict", as the distinction between the two is not always clear.

Exposure is a frequently used concept. It seems to measure the intensity of use of a transport system and the number of occasions during which vehicles, pedestrians, children etc. are exposed to accidents. It is used in two related manners. Firstly, to bring different systems to common denominator in order to facilitate a fair comparison of their safety. The central idea here is the elimination of differences in the intensity of use between the systems which are being compared. Secondly, to estimate the probability of accident per unit of use (single vehicle accidents per vehicle mile: pedestrian fatalities per road crossing etc.).

When it comes to specifics the concept of exposure becomes at times somewhat elusive. Consider, e.g., the crossing of a road by a pedestrian as a unit of exposure. Should road crossing when there is no vehicle in sight be counted into exposure? If yes, what is

the pedestrian exposed to? If only crossings with vehicles closer than a certain distance are to be included in exposure, is one not really speaking of conflicts?

If there is a difference of essence between the two concepts it seems to be rooted in the requirement that, for conflicts, the probability accident-given-conflict be the same for systems which are being compared. This implies, that for all systems which are compared, the ratio of (expected) number of accidents and the (expected) number of conflicts has the same numerical value.

With exposure, one hopes to achieve the opposite. When the expected number of accidents is divided by exposure, one intends to highlight the differences between the systems compared. It is precisely this difference between systems in the probability of accident per unit of use which is why exposure is introduced. Thus, for the concept of conflict to be useful, the number of accidents per conflict must be the same for all systems compared. For the concept of exposure to be useful, the number of accidents per exposure must be allowed to vary between systems. Consequently, the two concepts can not be identical.

Another distinction between the two concepts can be made in terms of their intended use. Conflict studies facilitate the estimation of the expected number of accidents occurring on a system per unit of time under a specific level of use. The output of a conflict study can be used in conjunction with information on exposure to obtain estimates of probability of accident per unit of exposure. This suggests a degree of complementarity and sequential ordering. First, information is obtained on the expected number of accidents for the systems; then it may be interpreted using information on exposure.

4. Consider the contemplated change in the duration of the amber period (Section 8) and for sake of specificity assume that its prolongation is suggested. Suppose also that a conflict is recorded whenever a vehicle is trapped by the amber signal inside the intersection. A conflict study would most likely conclude that the "conflict rate before" is much the same as the "conflict rate after". This leads to the conclusion that there has been no change in the expected accident rate. This may be erroneous. One may rightly suspect, that a conflict of this nature (trapped by amber) is less risky after the change. After all, the trapped vehicle has now more time to clear the intersection before the opposing traffic stream gets green light. Since the conflict definition used for the study violated the underlined statement in Section 11, an erroneous conclusion has been reached.

5. Continuing the illustrative example from above, let us redefine the occurrence of a conflict to mean the presence of a moving vehicle trapped by amber in the junction at the time the opposing traffic stream is moving. If now during the "before" study 200 conflicts are counted and in the "after" study 180, the indicated reduction in the conflict rate is 10 per cent suggesting the same reduction in the expected rate of accidents of this type.

There is good reason to expect that the prolongation of the amber period will create slightly longer queues, more stopping and possibly more rear-end accidents. A different conflict type (rear-end) used in a "before and after" study would also yield an estimate

of the relative change in the expected accident rate for rear-end accidents.

We have now estimates of relative change in two expected accident rates which are associated with a suggested prolongation of the amber period. To judge desirability, all consequences must be considered. However, relative changes do not lend themselves to joint consideration. For joint consideration one needs to know: how many, how severe. For this, estimates of A/C ratios are needed. More often than not, a change in the transport system affects not only the frequency with which different conflict types occur, it also eliminates some types and introduces new ones. (Guard rail installation, restriction of turning movements, street lighting etc.)

In this case, relative change has no meaning and safety needs to be measured in absolute terms.

6. The assertion that the central task of research is in the generation of a catalogue of A/C ratios requires clarification. Mostly, because this is not presently recognized as the main objective of research in this field.

Research on traffic conflicts has so far been oriented towards finding a practical method for conflict measurement and the demonstration that conflict counts are related to the occurrence of accidents and thus useful in their prediction. Investigations usually end with the determinaion of the coefficient of correlation and the testing of statistical hypothesis.

Concern about the sample coefficient of correlation proved to be confusing and at times frustrating. This is on the whole unnecessary. To examine the coefficient of correlation is to look at the right problem from the wrong angle. The tool chosen for examination determines the question asked, rather than the other way around.

Let us start the argument by contemplating the meaning of conditional probability. Specifically, of the conditional probability of an accident event to occur given that a conflict event has occurred.

What real information we have, pertains to the number of conflicts and the number of accidents which materialize during a certain period of time. We estimate the value of the probability "accident-given-conflict" through dividing the accident rate by the conflict rate. Thus, the conditional probability is an abstraction. It is defined to be the limiting value which the estimate would approach if conflicts and accidents were counted for a long period of time without any change in the prevailing conditions. It expresses our belief that the real accident generating system can be characterized by a stable property which is called probability. In our day this is not difficult to accept. Once we accept the existence of the accident event chain and of the associated permanent property - the probability "accident-given-conflict", all the important questions revolve around its estimation. What is the best estimate of the A/C ratio? What is the distribution of the A/C ratio?

Different definitions of the conflict event will be characterized by different conditional probabilities. To illustrate, let the expected two-vehicle-accident rates at a specific junction be 10 accidents per year. Let the expected number of events such that two vehicles come closer to each other than 2m be 10,000 per year. The conditional probability accident given conflict in this case is 1/1,000. Let there be 1,000 events per year such that two

vehicles are closer than 1 m. The associated probability is now 1/100. Both probabilities describe the same system. Their magnitude depends on the choice of the conflict event.

When those very same two conflict definitions are applied to another site, slightly different conditional probabilities may be obtained simply because no two sites are identical in all relevant factors. Thus, if many sites were examined, one might find that with 2m as the limiting value the conditional probability varies from 0.1/1000 to 2/1000 whereas with 1m as the limiting value the conditional probability is in the range 8/1000 to 11/1000.

This is the crux of the issue. One is not only, or even mainly, interested in the mean value of the A/C ratio but also in the distribution of this value among sites. A narrow distribution will allow accurate prediction a wide distribution is not very useful. A successful definition is one which yields estimates of A/C ratio from many sites such that they are closely packed around the mean value.

To illustrate, assume that a site survey indicates 20,000 conflicts defined by the 2m criterion. Considering the above mentioned range in the A/C ratio, one should expect 2 to 40 accidents per annum - not a very accurate prediction. In comparison, if using the 1m limiting value one would estimate 2,000 conflicts per annum, the estimate of accident rate would be 16 - 22.

Looking at research from the point of the eventual practical application of the conflict method seems to require that emphasis be placed on the estimation of the distribution of A/C ratios. As only narrow distributions of the A/C ratio will be useful, research has to identify conflict definitions which are likely to yield the same A/C ratio at different sites.

Examination of the coefficient of correlation does not seem to be required. True, when the A/C ratio varies widely among sites, the associated coefficient of correlation will be low and vice versa. It is the other face of the same coin. But why look at the tail of a coin if we are interested in the head? We have perfectly good measures to characterize the distribution of the A/C ratio or its spread (standard deviations, coefficients of variation, distribution of the slope of linear regression through origin etc.). These should be used in the search for the conflict definition and in the examination of the distribution of the conditional probability accident-given-conflict.

7. The very specific nature of the accident selected for illustration helps to focus discussion on concrete circumstances. Salient to this type of accident is the fact that one actor is "unaware" of the imminence or possibility of collision with another actor. This feature is common to a fairly large class of accidents; drivers unaware of pedestrians, children unaware of vehicles etc. In some cases, the methodology for conflict definition selection discussed below can be extended without difficulty to related types of accidents. In other cases (notably the "unaware" pedestrian case")it is not clear whether the method can be extended.

8. Some of the problems caused by the identifications of conflict occurrence with observation of evasive action have been discussed in paragraph 10. These can now be further illustrated within the context of the accidents between minor road "unaware" vehicles and main road traffic.

Consider, e.g., the cumulative distribution obtained from a field survey and shown in figure 6. Three drivers shot through the junction without deceleration. Evasive action was taken by one driver at 4m, another at 5.3m etc. Suppose that D^*=10m has been found to be the appropriate threshold value. By the definition in paragraph 23, 6 conflicts would have occurred. If; however, only events in which evasive action was observed, are recognized as conflicts, only three conflicts would have been counted. Such a count disregards the most telling events. Paradoxically, the more dangerous the junction, the more drivers might barrel through the junction without visible evasive action, the fewer the evasive action based conflicts would be.

9. The concept of "conflict" has been created to avoid estimation and observation problems which stem from the rarity of the accident event. It now seems that in some cases even conflict are rare and their value has to be estimated indirectly. One must therefore ask whether this "intermediate" concept is at all helpful?

It certainly is when a satisfactory conflict event can be defined which is also directly observable. If, e.g., research proves consistent existence of a relationship as shown in figure 4, estimation from field counts of conflicts may be feasible. When no satisfactory definition of the conflict event leads to relatively frequent conflict occurrence, the value of the concept is two-fold. Firstly, it does away with the need to model that phase of the event chain which takes place after the conflict till the accident. This is accomplished insuring that the factors affecting this part of the chain of events are common to the situations safety of which is being compared. Secondly, it poses a clear attainable goal to measurement, modelling and estimation.

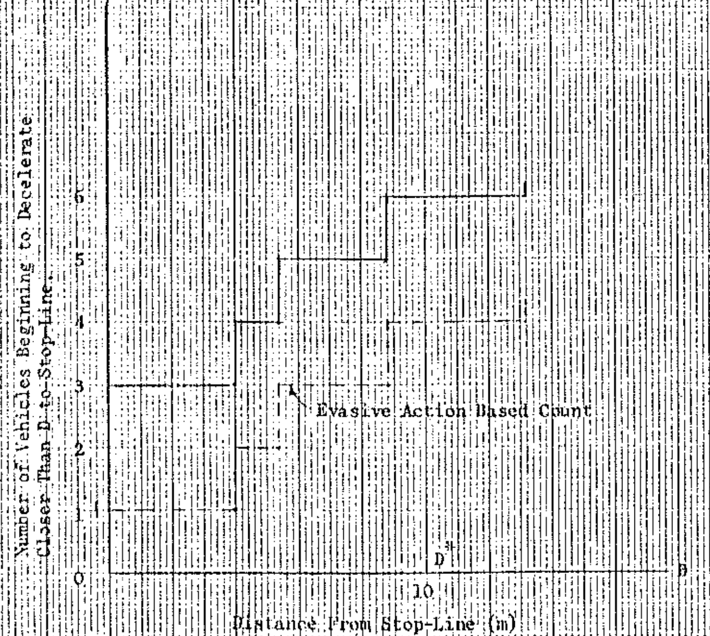

Figure 6. Bias in Count Due to Evasive-Action Based Conflict Definition