Analysing the amber dilemma problem using risk analysis techniques

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Abstract
This research aimed to determine the driver and signal factors that are most important in the occurrence of an amber dilemma conflict, by modelling the movement of two opposing vehicles at an intersection. Risk assessment software @RISK was used to allow model parameters to have a distribution of values instead of a fixed value. The scenario most likely to result in an amber dilemma crossing conflict was found to be the following (where Vehicles A and B are in opposing lanes):

- *Vehicle A in dilemma zone*
- *Vehicle B stationary at the limit line in lane furthest from Vehicle A*
- *Vehicle A having a low deceleration rate and large perception-reaction time*
- *Vehicle B having a low perception-reaction time.*

The results also show how the probability of a crossing conflict decreases significantly as the amber and/or all-red time increases. Many traffic problems would benefit from using a similar form modelling with risk analysis, where the variability present in real life driving situations can be included.

Introduction
Road accidents caused by red-light running make up a substantial proportion of urban road accidents. Red light running can be a deliberate decision by a driver, or the result of an inability to halt safely due to the amber dilemma. This research aimed to determine the combination of driver characteristics and signal timing that were most important in the occurrence of accidents arising from amber dilemmas.

The amber dilemma has traditionally been analysed from two different positions. The first, by Gazis et al. [1960] followed a deterministic approach. A vehicles movement approaching a signalised intersection was represented by kinematic equations and defined one amber dilemma zone and one option zone. The main weakness of this approach is that it did not account for the natural variation in driver characteristics, such as approach speed or reaction time. In Webster and Ellson's [1965] analysis this aspect was included, by defining a threshold amber distance probabilistically, based on experimental observations. Instead of a single option and dilemma zone being defined, a multitude of overlapping zones (one for each driver) was found for each approach speed.

This research on the amber dilemma aimed to determine what combination of driver and signal characteristics were most likely to result in an amber dilemma crossing conflict. The analysis is based on the deterministic approach taken by Gazis et al., but also includes a probabilistic component for the driver and signal variables in the kinematic equations. Using risk assessment software @RISK, parameters, such as approach speed, were given a distribution of values instead of one fixed value. This approach has both the analytical advantages of the deterministic approach and the higher level of realism found in the probabilistic approach.

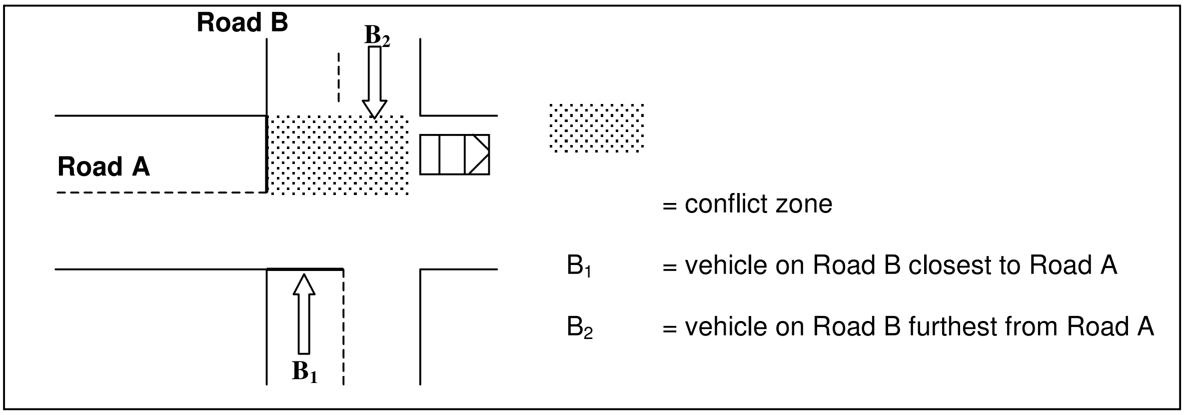

Figure 1: Model intersection layout

Research method

A model was developed that represents vehicle movement approaching and travelling through a signalised intersection (see Figure 1). By applying this model to two vehicles in opposing flows it can be determined whether the two vehicles will have an amber dilemma conflict.

For a vehicle on Road A, facing a signal that has just changed from green to amber, one of the following scenarios must apply:

Case 1: The vehicle is at a position such that it cannot travel through the intersection in time and so halts at the limit line.

Case 2: The vehicle is at a position such that it cannot halt at the limit line in time but can travel through the intersection safely.

Case 3: The vehicle is at a position such that it cannot halt at the limit line in time and cannot travel through the intersection safely [dilemma zone].

Case 4: The vehicle is at a position such that it can either halt at the limit line or travel through the intersection safely [option zone]. For this research it is assumed that a vehicle in the option zone halts at the limit line.

Similarly, for a vehicle on the opposing Road B, when their signal has just changed from red to green, one of the following scenarios must apply:

Case 5: The vehicle is stationary at the limit line and accelerates through the intersection.

Case 6: The vehicle is at a position such that it has not yet needed to decelerate for the red light and so travels through the intersection at cruise speed.

Case 7: The vehicle is at a position such that it has begun to decelerate for the red light. Once the light turns green the vehicle starts accelerating and travels through the intersection accelerating up to or at cruise speed.

The case that each vehicle is assigned to is dependent on its initial position, the driver characteristics and the amber duration. For example, two vehicles placed at identical initial positions could be assigned to different scenarios if their driver characteristics (i.e. perception reaction time) are sufficiently different. After a case has been assigned, the vehicles movement through the intersection is modelled by simple kinematic equations, calculated in an Excel spreadsheet.

For a vehicle on Road A, if Case 1, 2 or 4 applies there is no possibility of a conflict, while all cases on Road B could possibly result in a conflict if the vehicle on Road A is in the amber dilemma zone (Case 3). If a conflict is possible, the time each vehicle spends in the conflict zone is calculated. A traffic conflict is defined to have occurred if the two vehicles are in the collision zone at the same time.

The driver characteristics that are included in the model are as follows:

- intersection approach speed
- comfortable acceleration and deceleration rate
- perception-reaction time

As was discussed, it is desirable that the driver characteristics are not constrained by average values, but are able to represent the variability that is present in real life. This was achieved using the risk assessment software @RISK. Working "on top" of Excel, @RISK allows cells to be given a statistical distribution of values instead of one single value. For example, instead of a driver's perception-reaction time being defined by a cell value of 1.5 seconds, @RISK allows the cell to have a mean of 1.5 seconds and be normally distributed between a minimum and maximum value. Similarly, a vehicles position from the intersection was able to be defined as having a uniform distribution between some maximum distance and the limit line. After variables are assigned a distribution, a simulation can be run where @RISK performs multiple calculations (each determining whether a conflict will occur) with parameters varied according to their distribution. The output from the simulation includes the proportion of calculations that produced a conflict and the variables that were most significant in crossing conflict occurrence.

Research results

The scenario most likely to result in a conflict was found to be:

- Vehicle A in dilemma zone
- Vehicle B stationary at the limit line in lane B_2
- Vehicle A having a low deceleration rate and large perception-reaction time
- Vehicle B having a low perception-reaction time.

Vehicles on Road B_2 in Case 5 (accelerating from rest at the limit line) were involved in 80% of conflicts. While vehicles that had begun decelerating for the red signal, but hadn't halted, accounted for some 20% of conflicts (Case 7). Of note, vehicles that were sufficiently far away not to have begun decelerating (Case 6) didn't feature in a single conflict

When a vehicle on Road A had both a low deceleration rate and large perception-reaction time the likelihood of it being positioned in an amber dilemma zone (instead of an option zone) was greatly increased. When this scenario was combined with Vehicle B_2 having a short perception-reaction time (allowing it to reach the conflict zone more quickly) there was a greatly increased likelihood of a conflict.

If aiming to minimise the number of amber dilemma related accidents at an intersection, the two parameters that could be varied are the amber period and the all-red period. All other parameters are dependent on the driver and are not readily controlled. It was clearly found (see Table 1) that increasing the amber duration from 1.0 second to 3.8 seconds resulted in a substantial reduction in the probability of a crossing conflict. This is a useful demonstration of the effectiveness of New Zealand adopting an increased amber period of 3.8 seconds. The addition of 1.0 second all-red time (which in the model had the same effect as increasing the amber period) further decreased the conflict probability, from 0.01 to 0.0006.

Table 1: Conflict probability for varying amber and all-red times

amber time (s) (for zero all-red)	Conflict Probability	all-red time (s) (for 3.8 s amber)	conflict probability
1.0	0.34	0.0	0.01
2.0	0.17	0.2	0.0052
2.5	0.10	0.4	0.0032
3.0	0.05	0.6	0.0017
3.25	0.035	0.8	0.0010
3.5	0.02	1.0	0.0006
3.8	0.01	-	-

There is a need to consider the balance between increased intersection delay and potential accident reduction arising from increasing the inter-green time. The decrease in conflict probability and accident costs associated with an increase in inter-green duration above 4.8 seconds (3.8 seconds amber and 1.0 second all-red) is very slight and may well not be sufficient to justify the increase in intersection delay.

Conclusions

The aims of this research were threefold: to construct a model that determines if an amber dilemma conflict will occur; to apply @RISK as an analysis tool; and to determine the factors that are important in the occurrence of an amber dilemma conflict.

The construction of the model was successful within the limits of realism placed on it. True driver behaviour has not been replicated, especially in respect to driver reactions within the dilemma zone and approaching the intersection. A drivers willingness to stop, for example, was not allowed to vary. In addition, the driver characteristics, such as their comfortable deceleration rate, have not been rigorously investigated – “likely” or “reasonable” values have been used for the distributions. Post-graduate study that I am conducting will hopefully lead to more realistic values in this area.

@RISK was applied easily and successfully to the model. Once an Excel spreadsheet based on the model had been constructed it was an easy task to set distributions for the parameters and to run simulations. @RISK was a particularly intuitive program to use, and was also stable to run. @RISK is recommended for any analysis where uncertainty is involved.

The parameters that are significant in the occurrence of an amber dilemma conflict were able to be isolated. The value of knowing these parameters is not large in a practical traffic engineering sense, as most of them are unable to be readily controlled. However, it was very useful to establish a relationship between the probability of a crossing conflict and amber duration, as it vindicates the current use of a 3.8 second amber period.

References

Gazis, D., Herman, R. and Maradudin, A. The Problem of the Amber Signal Light in Traffic Flow. Operations Research, 8, 1960.

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