Crash risk estimation and assessment tool

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Abstract

Currently in Australia, there are no decision support tools for traffic and transport engineers to assess the crash risk potential of proposed road projects at design level. A selection of equivalent tools already exists for traffic performance assessment, e.g. aaSIDRA or VISSIM.

The Urban Crash Risk Assessment Tool (UCRAT) was developed for VicRoads by ARRB Group to promote methodical identification of future crash risks arising from proposed road infrastructure, where safety cannot be evaluated based on past crash history. The tool will assist practitioners with key design decisions to arrive at the safest and the most cost-optimal design options.

This paper details the development and application of UCRAT software. This professional tool may be used to calculate an expected mean number of casualty crashes for an intersection, a road link or defined road network consisting of a number of such elements. The mean number of crashes provides a measure of risk associated with the proposed functional design and allows evaluation of alternative options. The tool is based on historical data for existing road infrastructure in metropolitan Melbourne and takes into account the influence of key design features, traffic volumes, road function and the speed environment. Crash prediction modelling and risk assessment approaches were combined to develop its unique algorithms.

The tool has application in such projects as road access proposals associated with land use developments, public transport integration projects and new road corridor upgrade proposals.

Introduction

Planning and design of new road infrastructure is a balancing act of providing adequate traffic flow capacity, a safe road environment and complying with relevant road design standards – all to be delivered within limited budgets and timeframes. There are some tools to support transport professionals in achieving these goals. Software such as aaSIDRA, VISSIM and other modelling packages can estimate future traffic flow and delay impacts of proposed changes. To date there have been no dedicated decision support tools for estimating future road safety performance of proposed road infrastructure. This represents a significant gap in planning and design practice.

This paper details the development and application of a new software tool for identification of future casualty crash risk arising from proposed road infrastructure, where safety performance cannot be evaluated on the basis of past crash history. The Urban Crash Risk Assessment Tool (UCRAT) uses a combination of crash prediction modelling and crash risk assessment to estimate the expected number of casualty crashes for an intersection or a road link. A defined road network consisting of a number of such elements can also be evaluated using the software. The tool was developed for VicRoads by ARRB. VicRoads plans to apply UCRAT in safety evaluation of proposed road improvement projects.

UCRAT purpose

UCRAT was developed with the intent of assisting practitioners with key design decisions to ensure that:

•   potentially adverse effects of road project proposals on road safety are identified early
•   mitigating road improvement works can be clearly identified.

These aims are particularly relevant in the context of impacts of proposed land use developments. Most such projects result in traffic flow increases, which bring a reduction in safety performance if not

addressed through remedial design improvements. UCRAT provides a systematic way of evaluating future performance of such improvement options.

The tool is used to estimate the number of casualty crashes over a 5-year period for different functional design scenarios in a set reference year. The tool is intended for assessing urban intersection and midblock locations. A small road network can be assembled and the total crash estimate can be aggregated. Different design options can be compared this way. Two of many possible applications of the tool are shown in Figures 1a and 1b. The tool is aimed for use by planning and transport professionals with at least a basic level of expertise in road design and road safety.

Ideally, the casualty crash estimate for the selected option would be less or equal to the estimate for the existing conditions, adjusted for traffic flows in the reference year. This way, the requirement of the planning policies to avoid detriment to safety would be met. Where this is not possible (e.g. a greenfield site, constrained conditions), then a broader road network assessment should be carried out to identify mitigating road safety improvement works in the same area to compensate for the reduction in safety at one location. The tool may be used in safety assessment of various other proposed road projects, e.g.:

- planning of road extensions/duplications
- subdivision road network design
- traffic flow improvement projects
- recently constructed works.

In essence, the tool should be used in the evaluation of road project proposals where the future safety performance of the proposed design cannot be judged by the past crash records.
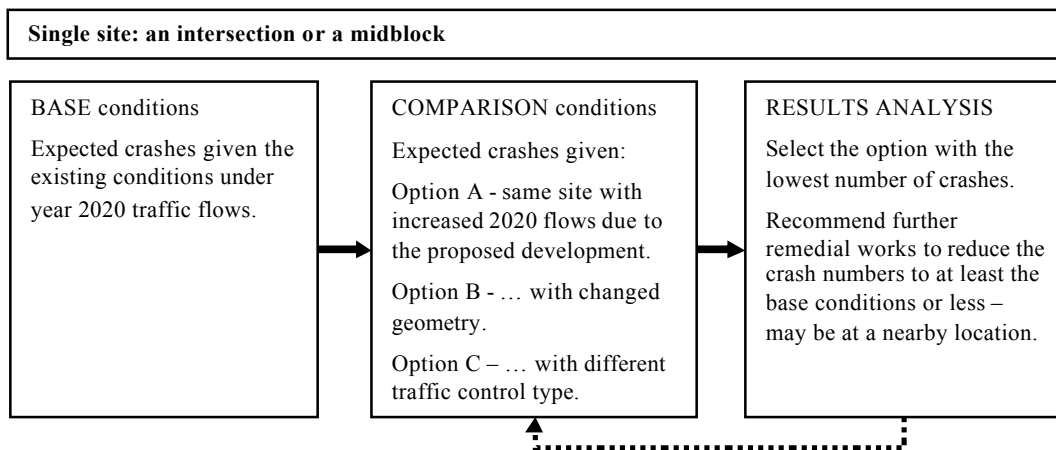
Single site: an intersection or a midblock

BASE conditions	COMPARISON conditions	RESULTS ANALYSIS
Expected crashes given the existing conditions under year 2020 traffic flows.	Expected crashes given: Option A - same site with increased 2020 flows due to the proposed development. Option B - … with changed geometry. Option C – … with different traffic control type.	Select the option with the lowest number of crashes. Recommend further remedial works to reduce the crash numbers to at least the base conditions or less – may be at a nearby location.

Figure 1a: Proposed application of UCRAT at a single site

Defined road network consisting of intersections and midblocks

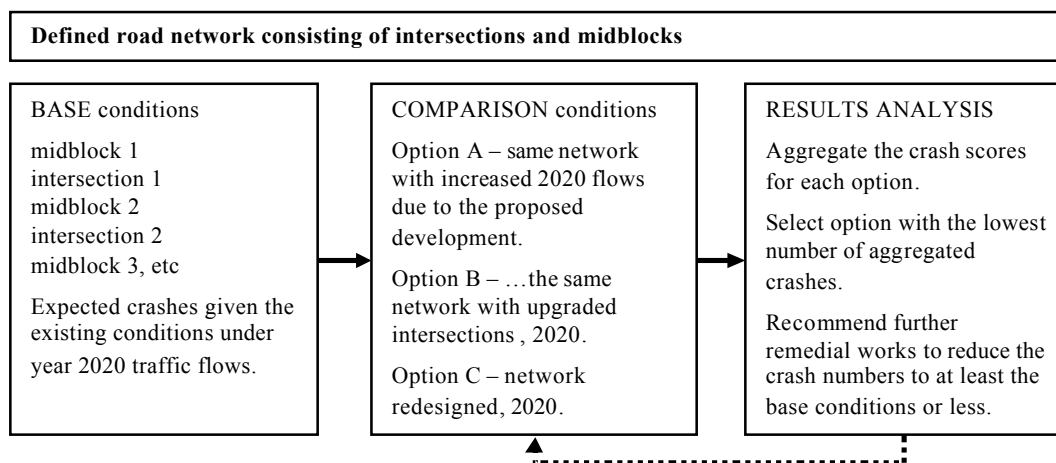| BASE conditions	COMPARISON conditions	RESULTS ANALYSIS
midblock 1 intersection 1 midblock 2 intersection 2 midblock 3, etc Expected crashes given the existing conditions under year 2020 traffic flows.	Option A – same network with increased 2020 flows due to the proposed development. Option B – …the same network with upgraded intersections , 2020. Option C – network redesigned, 2020.	Aggregate the crash scores for each option. Select option with the lowest number of aggregated crashes. Recommend further remedial works to reduce the crash numbers to at least the base conditions or less.

Figure 1b: Proposed application of UCRAT for a road network

UCRAT's crash estimates are referred to as the Casualty Crash Score (CCS). CCS should be seen as a long-term mean for the site, an indication of typical performance expected of similar sites – it is a rating of casualty crash risk rather than a precise prediction of how the site will behave over the next 5 years. In this context, any change in the score should be viewed as an indication of change in the level of safety. The indicative severity of the casualty crashes at the location is given by the Severity Score (SS). The CCS and SS values for individual sites can be aggregated for a defined road network if this method of assessment is used.

UCRAT processes

UCRAT uses a hybrid methodology of crash prediction and risk assessment, not unlike that used in the Highway Safety Manual (AASHTO, 1). Figure 2 shows the UCRAT model structure. The model is split into the midblock module and an intersection module. Each module is used to collect the input data relevant to the type, design and operation of each site. The network module may be used to aggregate completed assessments into a logical road network.
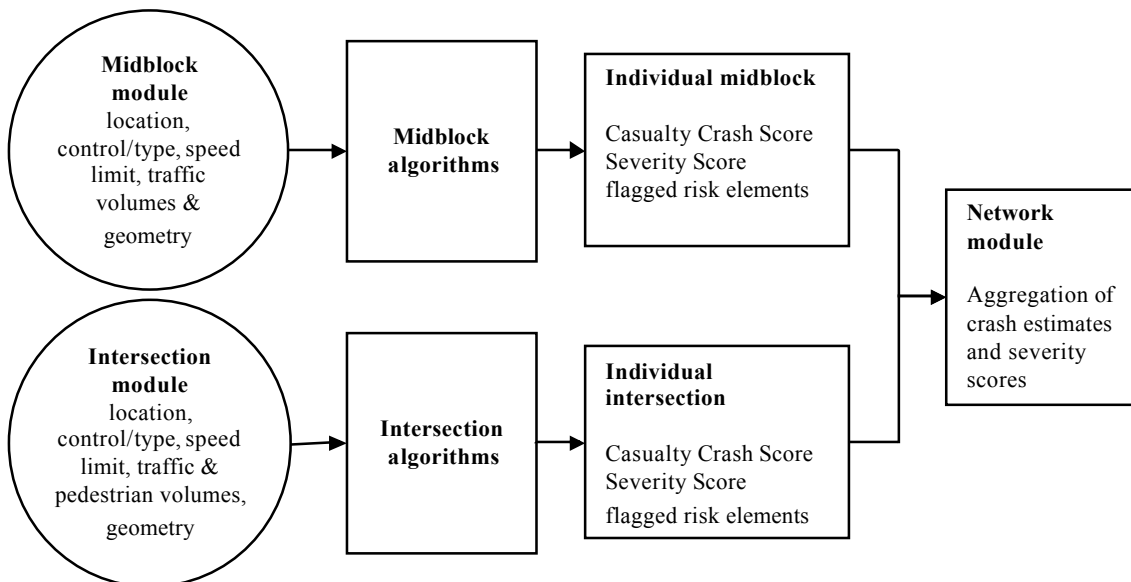
Figure 2: UCRAT model structure

The collected information about a midblock is saved and processed by algorithms to calculate the expected mean number of casualty crashes. The process requires the user to select the stereotype of the road, either divided or undivided – this determines which family of algorithms is used. Traffic movement flows (AADT) are also required at this point. Then the calculation of the total casualty crash estimate is split into six crash types: head-on, side impact, single vehicle, rear-end, pedestrians and other. The basic estimate for each of these crash types is calculated using a safety performance function (SPF) dependent on AADT only. SPFs are regression models estimating the mean number of casualty crashes of a given type per kilometre over a 5-year period. These models are based on metropolitan Melbourne casualty crashes (2002 – 2007), traffic volumes and road inventories. The models take form of power, exponential and linear relationships. Equation 1 is an example of an SPF for midblock undivided single-vehicle casualty crashes per kilometre:

$$SPF_{m\,sv} = 0.012\ AADT^{0.472} \qquad\qquad (1)$$

For each crash type, the mean crash estimate from the SPF is then multiplied by crash modification factors (CMFs). The role of a CMF is to adjust the crash type estimate in response to the inherent safety of a given road design feature. CMFs are relative risk values dependent on the presence and design level of these features. The design level of a feature corresponding to what is typically found on the network is

given a value of 1.00. When the feature's design level is better than average, in safety performance terms, the value falls below 1.00. When the feature is of poor standard or is not present, the CMF value is above one. In cases when a particular feature is not relevant to the likelihood of a given crash type, the value is set to 1.00.

The influence of the following road design features is accounted for using CMFs in modelling specific crash type estimates for midblocks:

- access density
- pavement friction
- approach grade
- frequency of hazards
- clear zone
- curvature
- pedestrian facilities
- parking.

In addition, several exposure-based CMFs have been developed to make adjustment for such variations as number of crossing pedestrians or the proportion of vehicles accessing the abutting land developments.

The CMF values were derived from various references, such as Elvik and Vaa (2), Turner, Turner and Wood (3), Turner, Styles, Jurewicz (4), Ogden (5) and Erke and Elvik (6). Also direct analysis was carried out on data extracted from QLIMITS 3.0 and VLimits 2.0 speed limit setting softwares. This provided a rich source of road feature, speed and casualty crash data leading to the development of several CMFs.

Once each crash type estimate has been adjusted by the relevant CMFs, the six products are added together and finally multiplied by the midblock length and the relevant calibration factor to give the final crash estimate, the CCS. Equation 2 is the general algorithm for calculating the midblock mean casualty crash estimate per five years.

$$CCS_m = L \times C_{ms} \times \sum_c (SPF_{msc} \times CMF_{m1} \times CMF_{m2} \times ...CMF_{m17}) \qquad (2)$$

where

CCS_m	= Casualty Crash Score for a midblock
SPF_{msc}	= safety performance function for a midblock stereotype and crash type (e.g. run-off-road casualty crashes on undivided urban roads)
CMF_{m1-m17}	= crash modification factors for midblocks relevant to each crash type
L	= midblock length
C_{ms}	= calibration factor dependent on the midblock stereotype (undivided/divided).

Calibration factors adjust for any systemic bias in the algorithms, e.g. differences in crash performance between the data set used to develop SPFs and the current crash performance. The factors are based on a calibration process of comparing the estimated crash values with the observed values for a number of real locations across a range of road and intersection stereotypes. Once calibrated, UCRAT's crash estimates were always within the 95% confidence interval of the observed crash mean values, and 83% of the sites were within one standard error of the observed means.

Algorithms for an intersection crash estimate work in a similar way to those for midblocks. There are three intersections stereotypes. Length is not used, as intersection SPFs already use a standard 100 m approach leg length. The intersection SPFs for each crash type (same as for midblocks) are based on entering volumes (EV), the sum of all approach movement AADT's. Equation 3 shows an example of an SPF for signalised intersection side impact crashes.

$$SPF_{i\,sig\,si} = 7x10^{-5}\,EV + 3.12 \qquad (3)$$

Each crash type estimate obtained from its SPF is multiplied by the relevant CMFs. The following design features are accounted for in the model using CMFs:

- approach traffic islands or medians
- right-turn control
- right-turn lanes
- left-turn lanes
- access density
- pavement friction
- approach grade
- frequency of hazards
- pedestrian facilities
- exposure-based CMFs.

The products of crash type SPFs and the CMFs are added together and the sum is multiplied by the relevant calibration factor to produce the intersection Casualty Crash Score. Equation 4 shows the general form of the algorithm.

$$CCS_{int} = C_{is} \times \sum_{c} (SPF_{isc} \times CMF_{i1} \times CMF_{i2} \times ... \times CMF_{i17})$$ (4)

where

CCS_{int} = Casualty Crash Score for an intersection
SPF_{isc} = safety performance function for an intersection stereotype and crash type (e.g. rear-end crashes at signalised intersections)
CMF_{i1-i17} = crash modification factors for intersections relevant to each crash type
C_{is} = calibration factor dependent on the intersection stereotype (undivided/divided).

Another element of the crash risk assessment is the estimation of the average severity of crashes which may occur in the future at each location, the Severity Score. The score is based on the relative unit cost of an average casualty crash based on the speed limits as provided by Perovic et al. (7). Where several speed limits are present, e.g. different intersection approaches, the model weighs the relevant Severity Scores by approach traffic volumes.

Functionality

The user interface of UCRAT consists of the main screen, the intersection module, the midblock module and the network module as shown on Figure 2. The main screen provides a gateway to other modules and allows the user to create new intersection, midblock and network assessments and to manage saved work as required.

The midblock module is used to collect the relevant input data and to display the calculated CCS and the SS scores. Figure 3 shows an example of a midblock assessment. The input data is processed immediately and can be saved to the database for future retrieval, copying and editing (e.g. to create an alternative functional design option for comparison of CCS scores). The module calculates the CCS and SS and displays it on the same page. This enables the user to experiment with combinations of different road features until satisfied that the safest design has been achieved within the known constraints.

Similarly, the intersection module is used to collect the necessary data about a section of road. The algorithms process this data as described in the previous section to produce the CSS and the SS. Figure 4 shows an example of the intersection assessment.

The network module allows the user to arrange the already created midblock and intersection assessments into a logical network of road links and nodes. The CCS scores are aggregated for the network to estimate the expected number of casualty crashes across the network. This is useful when creating a network option at a future point in time, e.g. existing scenario in a reference year, or an option representing a set of

proposed safety improvements. The SS is averaged across the network using a weight ratio based on each element's crash contribution to the total CCS. Figure 5 shows an example of a small road network consisting of a strip shopping centre.
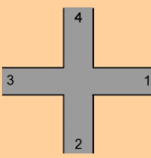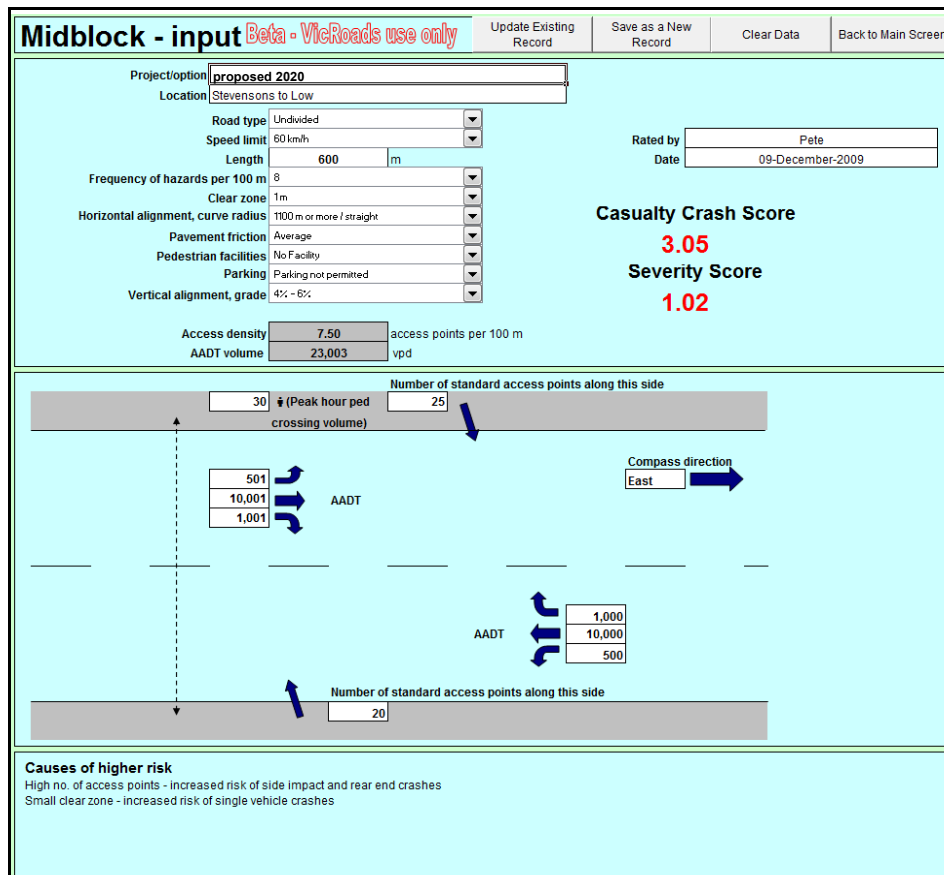

Figure 3: UCRAT's midblock module

Figure 4: UCRAT's intersection module

Figure 5: The network module aggregating the estimated crash performance of a proposed network option

Discussion

The paper has shown the need for a tool like UCRAT to evaluate crash performance of proposed road infrastructure. It is important to acknowledge the background research contributing to its development. UCRAT was based on the risk assessment experience arising from development and application of Road Safety Risk Manager and NetRisk. The six-year Road Safety Engineering Risk Assessment research program funded by Austroads provided the rich data sets which enabled development of the SPFs and fostered the development of the relevant analytical methodologies. Finally, the challenges faced by VicRoads during assessment of safety impacts of proposed road projects brought forward the research funding necessary to develop the tool.

As seen on the earlier figures, UCRAT is in beta release to VicRoads (the final draft). It will undergo further finetuning and recalibration based on the user feedback. To date the following areas have been identified for future investigation:

- refinement of SPFs, CMFs and calibration factors – adaptation of more evolved methodologies, e.g. intersection SPFs based on individual approach volumes
- further revision of the SS to reflect revised casualty costs
- conversion of the output casualty crash estimates to fatal and serious injury estimates – this will give UCRAT the ability to measure safety performance in the Safe System context
- economic evaluation option could be added, e.g. road trauma costs, BCR or NPV calculations for different options
- conversion to a web-based application to make the model accessible to more users and also secure (assessments of planning proposals may be commercial in confidence)
- expansion to a semi-rural and rural model to assist in evaluation of developments on urban fringes.

It is of particular interest to see if the tool will be successfully applied to provide win-win resolutions of differences between the road authority and land developers with improved road user safety as a result. Early examples of this were seen early during the UCRAT development process, where an early version was used in negotiations regarding design of several major new intersections in outer metropolitan Melbourne. Analysis using UCRAT provided quantified analysis of the safety benefits of providing relatively minor improvements (turning lanes) given a significant change in turning traffic volumes.

Conclusions

The UCRAT software tool has been created to provide a methodical approach to estimating the future casualty crash performance of proposed road infrastructure in urban environment. The tool uses a hybrid crash prediction modelling and risk assessment approach to estimate the number of casualty crashes (5-year period) based on traffic flow and the road features proposed. UCRAT can be used to evaluate alternative functional design options for intersections, road midblocks and entire road networks. Along with traffic flow modelling software, this tool should provide an important input into the overall evaluation of impacts of proposed land use developments and road improvements. A number of possible improvements and further developments have been identified to provide a path for the tool's further development.

Further information about UCRAT, its methodology, application and further development may be obtained from the lead author.

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