Australian National Risk Assessment Model: From vision to action

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Abstract

Crash risk assessment has developed gradually over the past 15 years to assist road agencies in identifying and treating road sections with high potential for future crashes. This paper presents the latest step on this journey: Australian National Risk Assessment Model (ANRAM) funded by Austroads and completed by ARRB Group in 2013. This paper provides an overview of the theory and research evidence supporting the model. It explains how the model operates to assess the risk of fatal and serious injury crashes. ANRAM provides a mechanism for quantifying and prioritising fatal and serious injury crash risk across the Australian road network. Identification of severe crash risk is based on assessment of road infrastructure, speed and traffic flow, and on severe crash history. The aim of ANRAM is to guide severe crash reduction programs to achieve progress towards a Safe System as effectively as possible. The paper discusses implications of ANRAM for road safety policy implementation and program funding in Australia. The paper concludes with a discussion of several possible directions for future development of risk-based road assessment models.

Introduction

This paper documents the development of the Australian National Risk Assessment Model (ANRAM). The model provides a mechanism for identification, estimation and reporting of severe (fatal and serious injury) crash risk across the Australian road network. The severe crash risk estimation is based on crash prediction models taking into account the relative safety of road infrastructure, speed, traffic flow, and potentially conflicting vehicle movements. Where available, severe crash history is used to verify and supplement the estimate of risk.

ANRAM's purpose is to guide future crash risk reduction programs on national, state and local road networks. Such programs could be based on treating the highest risk locations, route safety reviews, or network-wide mass-action treatments targeting selected types of severe crashes. ANRAM can also be used to monitor risk levels across the network over time. In such ways, ANRAM is ready to assist road agencies in achieving progress towards the Safe System.

Vision

Investigations of Victorian and New Zealand crash data showed that only a third of fatal crashes occurred in locations classed as black spots (Roper & Turner 2008). New Zealand data also revealed that more than half of fatal crashes occurred at locations where no other crashes had occurred in the previous five years. This scattering of severe crashes across the network suggests that if remedial attention was to be focussed only on black spots, the opportunity to prevent a large proportion of crashes would be missed.

Roper and Turner (2008) highlighted that the benefit-cost ratios of black spot projects have also been declining in recent years.

The *National Road Safety Strategy 2011-2020* (Australian Transport Council 2011) recognised the need to complement the traditional reactive road safety programs to build on Australia's road safety performance. The Australian Transport Council (2011) also acknowledged the wide dispersion of severe crashes across the road network and that a broader, more strategic approach to improving safety could be achieved by treating high crash risk road sections.

In its Safer Roads Directions statement, the Australian Transport Council (2011) stated that all levels of governments are to:

> …have assessed risk on their road network and re-focused road investment programs to treat higher-risk sections of the road network (road segments, traffic routes and defined areas) in addition to more targeted black spot programs. (Australian Transport Council 2011, p 54)

Action number 6 in the First Steps of the strategy, to be undertaken within the first three years (i.e. by the end of 2013), states the objective is to:

> Complete Austroads risk-based assessment model; and then, systematically assess risk levels for highest volume roads and prioritise road sections for safety improvement. (Australian Transport Council 2011, p 55)

There has been a growing level of interest in crash risk assessment in recent years by some road agencies. ARRB previously contributed to a number of general and specialised systems aimed at identifying high-risk locations and prioritising safety treatments (e.g. NetRisk, AusRAP, Road Safety Risk Manager, or SchoolRisk). Given this divergence, there was a need for a nationally-agreed model for adoption by road agencies across the country.

To fulfil these commitments, Austroads funded a three-year research and development project to develop a risk assessment model for use by road agencies at all levels of government. ARRB was charged with the task of drawing on recent research, best practice and stakeholder inputs to develop an appropriate model. ANRAM (v1.0) was completed in mid-2013 as Excel-based software and distributed to road agencies for implementation.

Research evidence and theory

Development of ANRAM began with a review of existing crash risk assessment practice in Australia and around the world. The review focussed on methodologies which sought to quantify casualty crash risk with the view to prioritise road sections and/or intersections for further investigation and treatment. The review was aimed at informing further discussions with the road agency road safety experts who were stakeholders in the ANRAM project.

During the early stages of the project, a number of established and emerging approaches were identified, which included NetRisk, Sustainably-safe Index, iRAP/AusRAP[1] and various crash-predictive methods (Turner et al. 2011). The most important findings followed from publication of the Highway Safety Manual, or HSM (AASHTO 2010).

HSM summarised two decades worth of research into crash prediction and crash reduction. It proposed a methodology for estimation of crash frequency changes following road infrastructure improvements. The basic approach of HSM is to estimate the mean number of crashes for a given type of road based on a simple traffic flow (AADT) crash prediction model, also known as a safety performance function (SPF). Such models can be developed from crash data referenced to individual road sections of known length and traffic flow. Such basic models are capable of accounting for the majority of change in mean crash frequency, as AADT is one of the strongest factors influencing crash occurrence.

[1] The International Road Assessment Programme and its Australian brand, AusRAP.

HSM proposes that the individual variation from the mean crash frequency may be due to each location's variation in road features and operational factors from the mean represented by the model, and due to statistical error. AASHTO (2010) proposes to use crash modification factors (CMFs) to account for the differences in crash frequency arising from the road environment. CMFs can be calculated in many different ways. The main sources of CMFs have been evaluations of road safety treatments which produced crash reduction factors. More recently, multivariate regression crash prediction models have been used to estimate CMFs for many key road environment factors (Schermer et al. 2011).

HSM documents in some detail the development of CMFs for various geometric road features, traffic management devices and operational factors (road attributes). Most have been sourced from past evaluations of road safety treatments, or were derived from more complex crash prediction models. Further publications offer more detailed guidance on their development in the context of HSM (Gross, Persaud & Lyon 2010).

CMFs are used to adjust the predicted mean crash number as illustrated in Equation 1 based on AASHTO (2010). In HSM and most other sources, CMFs above the value of 1.00 indicate that a given road attribute increases crash occurrence. Values below 1.00 suggest a reduction in crashes. Multiple road attributes can be recognised at a given road location in this way.

$$N_{predicted} = N_{SPFx} \text{ x } (CMF_1 \text{ x } CMF_2 \text{ x } CMF_3 \text{ x } \ldots \text{ x } CMF_n) \text{ x } C_x \text{ x } L \quad (1)$$

where

$N_{predicted}$ = predicted average frequency for a specific time period for a given road length

N_{SPFx} = predicted average crash frequency estimated from an SPF for a road stereotype x

CMF_1 to CMF_n = CMFs for specific existing road features from 1 to n

C_x = calibration factor adjusting the SPF to local conditions

L = length, typically in kilometres.

The actual observed crash performance can be used to augment the predicted value. The process is known as Empirical Bayes approach, where the statistical robustness of the SPF model and the predicted crash value are taken into consideration in assigning the weight given to the observed crash value. Doing so produces a more reliable estimate of the expected crashes (Nexpected) than either crash value alone. AASHTO (2010) provides detailed guidance on this process.

A road safety treatment scenario can be evaluated by applying relevant CMFs to expected crash value, as shown in Equation 2 based on HSM.

$$N_{after} = N_{expected} \text{ x } CMF_{t1} \text{ x } CMF_{t2} \text{ x } \ldots CMF_{tn} \quad (2)$$

where

N_{after} = the expected number of crashes after application of treatments

CMF_{t1} to CMF_{tn} = CMFs for the road features proposed as treatments.

The expected 'before' and 'after' results can be compared and economically evaluated against the project costs.

Overall, the HSM approach documented in AASHTO (2010) was recognised as the most theoretically robust method of accounting for road infrastructure-based crash risk on the Australian road network. It offered an opportunity to develop Australian crash prediction models based on fatal and serious injury crashes. These could be supplemented by local and internationally sourced CMF values, based on severe crashes where available. Such an approach directly supports the Safe System vision and objectives of the National Road Safety Strategy (Australian Transport Council 2011).

It was recognised by the ANRAM stakeholder group that AusRAP risk algorithms already provided a valuable method for identifying crash risk and could be applicable in the context of the project.

AusRAP risk algorithms bring together numerous standardised CMFs for different road attributes, and make them applicable to any road location. The road attribute CMFs were drawn from leading international crash risk research (iRAP 2013). Additionally, AusRAP risk algorithms provide some adjustment for increased severity of crashes in high-speed environments, and for increased crash occurrence where conflicting road user movements are more frequent. It is important to note that the underlying philosophy of AusRAP is that the lowest relative risk value is set to 1.00. This differs from the approach taken in HSM and many other sources using CMFs.

AusRAP's process of combining CMFs is a mechanistic model based on the likelihood of sub-components of three vehicle crash types:

- run-off-road: loss of control to driver and to passenger side
- head-on: loss of control and overtaking
- junction: intersection and property access.

Figure 1 shows an example of a total CMF for run-off-road to the driver side. AusRAP refers to these total CMFs for each crash sub-component as SRSs, or star rating scores. AusRAP adds these SRSs to form the total vehicle SRS for a given road segment. The total vehicle SRS is a numerical value representing a relative likelihood of a severe crash for a given road segment. Pedestrian, motorcyclist, and cyclist SRS models are also provided within AusRAP.

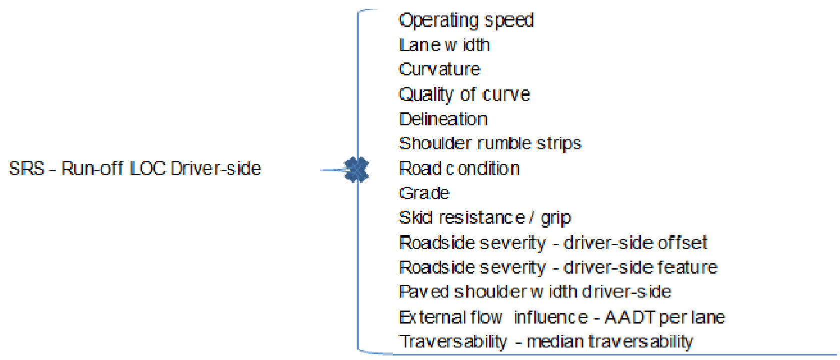


Figure 1. Part of the AusRAP (v3 Beta3) risk algorithm for run-off-road crash risk

AusRAP risk algorithms drew on previous Austroads research carried out by ARRB and were successfully trialled in Australia. The risk rating score produced by AusRAP provided a reasonable correlation to casualty crash rates (iRAP 2011). The success of KiwiRAP in providing a close fit to historical crash performance provided further confidence in the use of AusRAP algorithms (New Zealand Transport Agency 2011). It was also considered that development and trialling of a new CMF-based model would cause duplication and diversion in risk assessment practice in Australia.

Based on the review of the evidence, the project stakeholders agreed that AusRAP risk algorithms should be considered for inclusion in ANRAM.

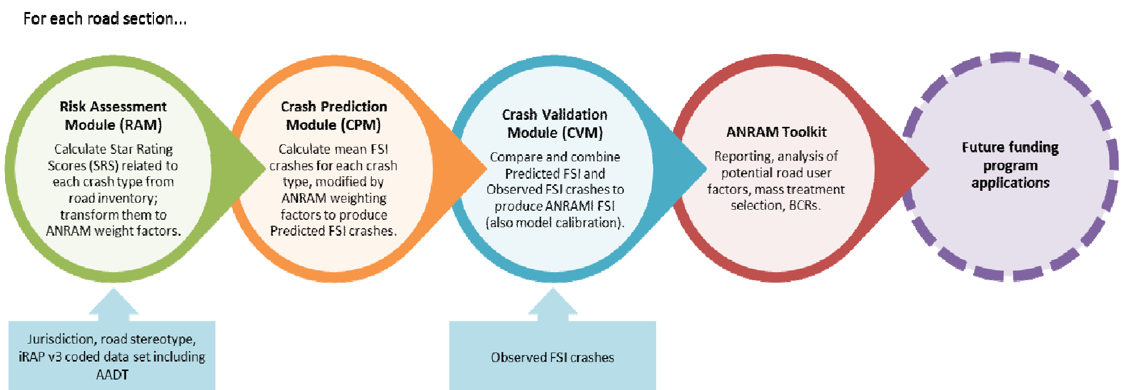
How ANRAM works

Development of ANRAM involved combination of the HSM and AusRAP approaches. The aim of the resulting model was to enable Australian road agencies to estimate and prioritise severe crash risk across the entire road network.

ANRAM was developed in close consultation with the road agencies and Australian Automobile Association (AAA) to ensure that the model's outputs could drive preparation of future mass-action road safety programs. This was especially important for rural and local roads where severe crashes are generally too scattered to attract traditional black spot funding.

Figure 2 shows the ANRAM flow chart. The process begins in the Risk Assessment Module with use of AusRAP algorithms to develop ANRAM-specific SRS values for five different crash types: run-off-road, head-on, intersection, pedestrian and other. The calculations are initially carried out at a 100 m road segment level. The values are then averaged at a road section level, typically 3 km.

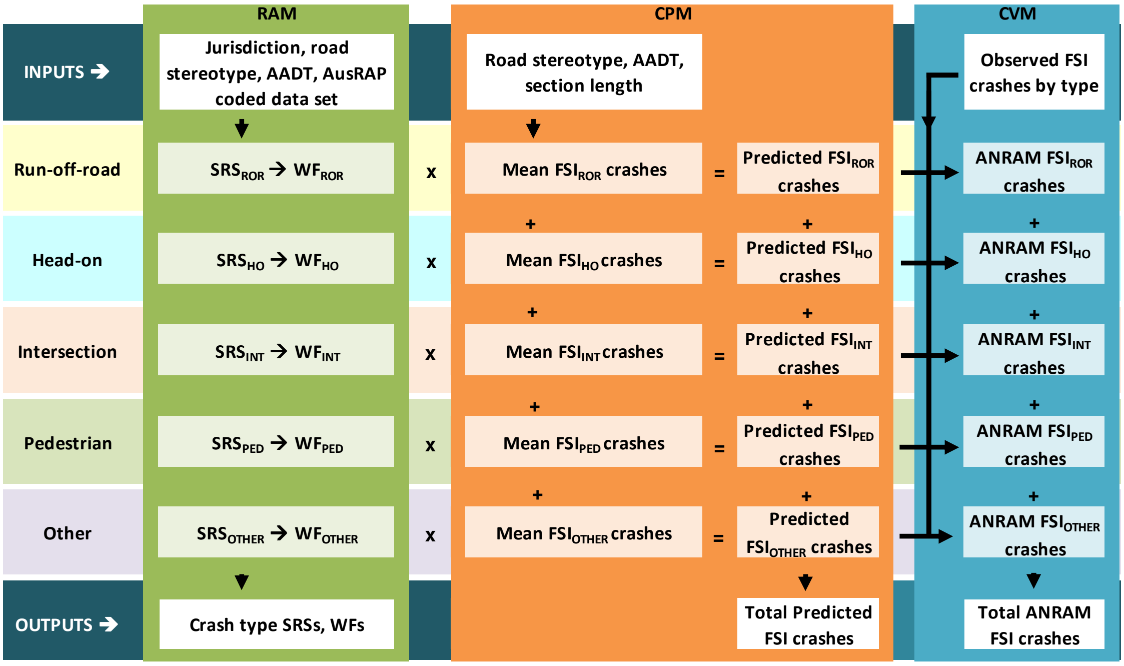
In order to translate the AusRAP definition of CMF value of 1.00 (lowest risk) to that of HSM (mean risk), these average SRS values are divided by the network-wide SRS averages for each crash type and road stereotype. These averages were developed from trial Australian data. This generates a crash-type-specific Weighting Factor, an equivalent HSM-like CMF, for an individual road section given its road features, speeds and potential for conflicting movements.



Source: Jurewicz, Steinmetz and Turner (2013)

Figure 2: ANRAM structure

The Crash Prediction Module uses safety performance functions (SPFs) based on Australian data, to calculate a mean number of fatal and severe injury (FSI) crashes for each of the five types, given the road stereotype (see Equation 1). There were 30 such SPFs developed for this purpose: 5 crash types, 6 road stereotypes. For each road section and crash type, the calculated mean is adjusted by the Weighting Factor. If the road has low risk attributes the Predicted FSI for a given crash type will be below average. If the road attributes indicate high crash risk this will be reflected in a high Predicted FSI value. Figure 3 shows the matrix which illustrates the concept.



Source: Jurewicz, Steinmetz and Turner (2013)

Figure 3: Schematic representation of calculations in ANRAM's RAM and CPM

The resulting Predicted FSI crash values represent the estimate of severe crash risk based only on road infrastructure, speed and potential for conflicting movements. They do not account for such localised crash factors as high incidence of fatigue, speeding, or an unusual mix of road users. The Crash Validation Module accounts for this risk by using crash history, or Observed FSI crashes.

ANRAM's Crash Validation Module uses the Empirical Bayes approach described earlier to reconcile Predicted and Observed FSI crashes for each road section and crash type. The ANRAM FSI crash values are produced through a weighted average of predicted and observed crash values, as illustrated in Equation 3. The weighting factor (w) is based on the Predicted FSI crashes and the SPF model strength (Equation 4). Where predicted crash values are low, the observed crashes are also likely to be infrequent and likely to suffer from a great deal of random error. In such case, more weight is given to the Predicted FSI value. However, where significant crashes are predicted, the Observed FSI crash numbers are likely to be higher and more robust, and are thus given more weight. In this way, the more statistically robust estimate of risk is given a greater weight in calculation of ANRAM FSI crashes for each road section.

$$\text{ANRAM FSI}_i = w \text{ x Predicted FSI}_{ij} + (1\text{-}w) \text{ Observed FSI}_i \quad (3)$$

where

ANRAM FSI_i = the expected fatal and serious injury crashes for crash type i in the given road section

w = Bayesian weighting mechanism dictating how much emphasis is given to Predicted FSI or Observed FSI as expressed by Equation 4

Predicted FSI_{ij} = predicted FSI for crash type i for a given road section of stereotype j based on its traffic flow, specific road attributes, speed and potentially conflicting traffic

Observed FSI_i = observed fatal and serious injury crashes for crash type i in the given road section

$$w = \frac{1}{1 + k \times \text{Predicted FSI}_{ij}/L} \quad (4)$$

where

k = overdispersion factor, a statistical parameter derived during regression of crash data to create the SPF

L = section length in kilometres.

ANRAM FSI crashes are the main output of the model, although the interim outputs are also useful to road agencies. For example, ANRAM SRS values can be used to rate safety of roads in a similar way that AusRAP SRS are used to derive the star rating.

The ANRAM FSI crash estimate provides a sound assessment of severe crash risk for a given road section, expressed in the currency of the Safe System, i.e. fatal and serious injury crashes. ANRAM FSI also quantifies the role of road infrastructure in this risk.

ANRAM was trialled on over 1000 km of roads of different stereotypes across most Australian states. The data from the trials informed the selection of model calibration factors ensuring that the model outputs are relatively close to the observed values.

Application

ANRAM provides a Toolkit to make it easier for road agency users to apply the model and carry out useful analysis of severe crash risk across the road network.

The Toolkit outputs various risk parameters, e.g. ANRAM SRS, Predicted FSI crashes or ANRAM FSI crashes, making it relatively easy to isolate road sections with particularly high overall or specific types of crash risk. Also, the Toolkit allows users to find out which specific road attributes contribute to this risk (e.g. lack of sealed shoulders).

Knowing this, users can easily compile a hypothetical treatment program targeting the key high-risk attributes. Such program may involve installation of safety barriers on sharp curves, delineation improvements, intersection upgrades or installation of pedestrian facilities. The Toolkit then recalculates the Predicted FSI crashes for the chosen treatment scenarios. By comparing the before and after Predicted FSI crashes, ANRAM can calculate the program-wide crash reduction factor, and use the provided costing to estimate the program BCR.

Road agencies may use their own approaches to treatment selection. The ANRAM Toolkit is open-ended in this regard in recognition of each jurisdiction’s specific conditions and resources.

Local roads and low volume roads in regional areas have had limited access to traditional road safety funding through black spot programs. The scattered nature of severe crashes made it difficult to reliably identify high-risk sections, and even more difficult to economically evaluate effective treatments. ANRAM’s approach to severe crash risk estimation makes it easier to develop and estimate benefits of low-cost targeted mass-treatment programs on these local and low volume regional roads.

This approach supports development of future funding programs based on proactive treatment of high-risk sites. By treating the highest severe crash risk road sections first, road networks will progressively attain performance closer to the Safe System goal.

Implementation

ANRAM was commencing the implementation phase at the time of writing. A number of implementation opportunities were identified at the time. These were:

- Data collection. The AusRAP model requires collection of 76 road attributes for each 100 m road segment (46 risk factors). Thus, data collection and coding may represent a significant effort and cost. Two road agencies, Department of Planning, Transport and Infrastructure in South Australia, and Main Roads Western Australia, have undertaken feasibility trials to adapt their already existing road inventory attributes to AusRAP standards. Both resulted in the creation of ANRAM-ready data sets, their evaluation and analysis of severe crash risk.

  The scope of data collection represents a challenge for local government road agencies with limited budgets. To address this, an investigation of simplified or part-estimated road attribute data sets was proposed.
- Pilot projects in jurisdictions. The model requires ongoing refinement in order to provide increasingly robust results. More data from diverse jurisdictions is required. To date, Main Roads Western Australia has undertaken an implementation pilot of a 400 km section of a remote rural highway.
- Ongoing software development. Under the Austroads project, ANRAM was developed as an Excel spreadsheet application. It is intended to integrate it into iRAP's ViDA online software platform to standardise processing, project reporting, and to maintain convergence of the risk algorithms.
- Training. ANRAM and risk assessment is an emerging area of road safety for many practitioners and decision makers. In support of the ongoing implementation of ANRAM, ARRB is delivering a series of training workshops to provide a skill base in the use of ANRAM across Australia.
- ANRAM has met the challenges set by the National Road Safety Strategy to provide a way for measuring the levels of crash risk across the nation's road network. Thus, ANRAM provides a vehicle for the introduction of national or state-based funding programs targeted at minimising severe crash risk on the road network.

Conclusions

This paper has outlined the need for a national level risk assessment model to assist road agencies in proactive identification and treatment of severe crash risk on the Australian road network, in order to progress towards the Safe System.

The theoretical base for the model was a combination of the HSM and AusRAP approaches. The resulting model, ANRAM, combines the robustness of the fatal and serious injury crash prediction modelling with the versatility of a risk assessment model. ANRAM uses the same road attribute coding as AusRAP, plus information about road stereotype and jurisdiction, and observed crash history, to estimate the expected fatal and serious injury crashes for any road section evaluated (ANRAM FSI crashes).

ANRAM can be used to model future benefits of road safety infrastructure programs. The ANRAM Toolkit estimates the expected crash savings, the project and program-level BCRs.

Jurisdictions are now encouraged to undertake pilot projects of ANRAM to trial its implementation across the country. In doing so, data acquisition processes will be refined resulting in the reduction of costs. Pilot projects will also provide first-hand experience in the use of ANRAM and evaluation of proactive road safety programs. In time, ANRAM may evolve towards an online platform.

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