Available online at www.sciencedirect.com
ScienceDirect
Transportation Research Procedia 14 (2016) 2101 – 2110
Transportation Research Procedia
www.elsevier.com/locate/procedia
6th Transport Research Arena April 18-21, 2016

Application of a crash-predictive risk assessment model to prioritise road safety investment in Australia

Chris Jurewicz [a,*], Rita Excel [a]

[a] *Australian Road Research Board, Vermont South, 3133, Australia*

Abstract

Australia experiences many similar strategic road safety challenges as most European countries. These include the objective to strongly reduce fatalities and serious injuries, budgetary constraint requiring prioritisation of road investment, and the growing need for improved integration of road transport to drive efficiency. The current National Road Safety Strategy 2011–2020 aims for a 30% reduction in fatal and serious injuries, a step on a path towards the Safe System (Vision Zero). This aim is made more challenging by the geographically scattered nature of fatal and serious (severe) crashes on the road network, especially on routes with moderate traffic flows or in regional areas. This problem has led to reducing economic returns from conventional road safety initiatives based on treatment of crash-cluster locations or lengths.
This paper shows how the Australian National Risk Assessment Model (ANRAM) addresses this challenge and assists state road agencies to meet the aims of the national strategy. ANRAM is used by the agencies to assess the risk of future severe crashes across their road networks. It is then used to prioritise those sections based on severe crash estimates, less susceptible to random variation (the scatter). The model facilitates creation of strategically-aligned infrastructure investment programs to reduce the severe crash risk and to estimate future crash savings. These are used together with program capital costs to carry out economic analysis and to support funding decisions.
The paper outlines how ANRAM uses a crash-predictive approach to first estimate mean severe crashes per road section, by crash type. Then, it shows how ANRAM adjusts the estimate using risk algorithms which build on the International Road Assessment Program (iRAP) protocols. These algorithms use detailed road attribute data and research evidence about crash risk potential associated with road design/infrastructure, traffic speeds, and likelihood of vehicle conflicts. Finally, the model uses historical severe crash data in an Empirical Bayes validation technique to provide additional confidence in the estimates.

* Corresponding author. Tel.: +61 3 9881 1612.
E-mail address: chris.jurewicz@arrb.com.au

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.225

ANRAM has enabled Australian road agencies to scope and prioritise proactive road safety investment options before severe crashes form a historical data clusters. The paper presents several examples of recent programs which reflect jurisdictional priorities, unique local conditions and available resources.

The paper concludes with a discussion on how the approach used in ANRAM could have relevance to effective programming of road safety investment for European road agencies. It also suggests additional benefits beyond road safety, e.g. though providing inputs into road data inventories used in transport modelling.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: ANRAM; Safe System; Vision Zero; crash prediction; crash risk assessment; road safety program

1. Introduction

Australia experiences many similar strategic road safety challenges as most European countries. In a typical year, 1200 Australians lose their lives in road transport crashes (Lydon et al. 2015), and further 33,000 are seriously injured (Australian Institute of Health and Welfare, 2015). Australian state and federal road transport agencies work together to address this problem. The National Road Safety Strategy 2011–2020 has set an ambitious target for a 30% reduction in fatal and serious injuries (Australian Transport Council 2011). Halfway through this strategy, it appears that its objectives are being met through vigorous activity on all fronts: targeted road infrastructure improvements, improved driver licencing and training, vigorous law enforcement, and improved new vehicle safety standards (Lydon et al. 2015).

The investment in safety related road infrastructure improvement is strongly dictated by budgetary constraint requiring prioritisation of road investment and the growing need for improved integration of road transport to drive efficiency. Another feature of the Australian effort is the strategic commitment to Safe System, a philosophy similar to the Swedish Vision Zero, which seeks to minimise death and serious injury. This aim is made more challenging by the geographically scattered nature of fatal and serious injury (severe) crashes on the road network, especially on routes with moderate traffic flows or in regional areas. This problem has led to reducing economic returns from conventional road safety initiatives based on treatment of black spot/crash-cluster locations or lengths.

This paper shows how the Australian National Risk Assessment Model (ANRAM) has been developed to address these challenges in improving safety of road infrastructure. It is demonstrates how ANRAM assists state and local road agency practitioners in assessing risk of severe crashes on their road networks and prioritising road safety infrastructure programs to meet the aims of the national strategy.

2. Background

As far back as the late 1980s, road safety audits established a practice of identifying crash risk and prioritising proposed treatments using simple guidelines. By the early 2000s, first tools were being developed to systematically manage audit outcomes by calculating crash risk scores and objectively prioritising treatments. Road Safety Risk Manager (RSRM) was developed and continues to be used by state and local road agencies to assess crash risk at individual locations. In mid-2000s, NetRISK was developed in Queensland using similar principles to provide a network-level crash risk assessment of road features to prioritise sites for further detailed auditing. Shortly after, the first versions of AusRAP/iRAP[1] were developed expanding the power and features of crash risk assessment by introducing star ratings based on inherent level of road infrastructure safety, estimating fatality reductions and benefit-cost ratios (BCRs) of road infrastructure improvement programs.

Consecutive versions of AusRAP, and its New Zealand counterpart the KiwiRAP, refined the risk models to provide improved responsiveness to emerging road safety treatments. By 2009, the crash risk assessment practice

[1] AusRAP is an Australian application of iRAP – it uses the same risk algorithms and software.

was maturing and was applied nationally in Australia by auto clubs to lobby for additional road funding. At the same time, alternative crash site prioritisation and crash risk assessment approaches were being developed by state road agencies to drive road safety program development. There was a risk of fragmenting into competing systems in response to different needs of road agencies and auto clubs.

At this point, ANRAM was funded to provide Australian road agencies with a nationally-consistent risk-based road assessment program while maintaining convergence with AusRAP, the preferred tool of the auto clubs. ANRAM's development was guided by the objectives of the National Road Safety Strategy 2011–2020 (Australian Transport Council 2011). These objectives specifically called for development of a risk-based system to identify high-risk road sections and to prioritise them for treatment – a significant task for a large country like Australia. Another requirement guiding ANRAM development was utilisation of highly-developed crash databases available in all Australian jurisdictions. Ability to target priority crash types identified by the National Strategy was also noted as a priority.

The Safe System vision seeks eradication of fatal and serious injuries in road transport. This represents a shift in the old paradigm from targeting all casualty crashes. Thus the new strategy dictated a change in the methods for identifying and evaluating crash risk. Severe crashes are less likely to cluster at specific sites, or may appear randomly scattered, especially on rural and other lower volume road networks. Statistical analysis is also less robust due to small crash samples. This makes it more difficult for road agencies to estimate severe crash risk from past records in crash data bases. Traditional approaches to development road safety programs based on crash clusters (black spots, black lengths) may struggle to accurately prioritise treatment projects based on small numbers of severe crashes. Such approaches are most successful in high-volume road environments where severe crashes occur in statistically significant numbers. Thus, ANRAM v1.0 was developed to complement these traditional approaches to road safety program development as shown in Figure 1.

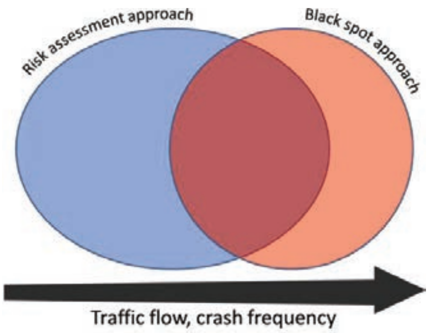

Fig. 1. Complementary roles of crash risk assessment and black spot approaches in road safety program development.

Development of ANRAM v1.0 occurred between 2009 and 2014 and was led by the authors with Austroads and ARRB funding, under the direction of state road agencies. Significant contribution was received from iRAP in the form of risk algorithms and guidance. The second development phase begun in 2014 and is expected to continue until the end of 2016.

3. How ANRAM works?

ANRAM v1.0 has many broad conceptual similarities with the Highway Safety Manual (AASHTO 2010). It is a hybrid model driven by practical needs to evaluate severe injury crash risk and assign treatments, and by sound statistical theory. ANRAM v1.0 uses road feature risk assessment and crash prediction models to identify road sections with high risk of severe injury crashes. Figure 2 shows the process flow from data upload in the risk assessment module (RAM) to development of road safety program options in The Toolkit.

Risk estimation in RAM is driven by relative safety performance of road infrastructure, traffic speed, and potential for vehicle conflicts. RAM utilises iRAP risk algorithms to achieve this. The algorithms assign relative crash risk to each road attribute category derived from literature reviews (iRAP 2015). These relative risks are equivalents of crash modification factors (CMFs) used in the Highway Safety Manual. For instance, a roundabout has a lower relative crash risk value than a priority controlled intersection to reflect lower risk of casualty crashes at roundabouts. There are 44 road attributes in ANRAM which affect the risk score produced by the iRAP algorithms.

Significant amounts of data are required for input to the model. Road and traffic flow attributes for each 100 m road segment on the network are coded from digital video acquired by data collection vehicles. The risk score is calculated for each road segment. Road segment risk scores are aggregated to a road section level (1–3 km) and then compared to the national average for the given road stereotype. This determines if a given road section is low, average or high-risk (e.g. weighting of 1.9 times the average). This simplified description of the risk assessment process is fully documented in Jurewicz and Steinmetz (2014).

In the crash prediction module, Crash Prediction Module (CPM) in Figure 2, the road section weighting based on risk scores is applied to crash-predictive models (referred to as safety performance functions in the AASHTO 2010). These SPFs are AADT-only severe crash frequency models developed from Australian crash data bases and traffic flow records provided by state road agencies (AADT). SPFs are crash-type and road stereotype specific. Thus, SPF's mean severe crash count estimate per section is augmented by the section's individual weighting to produce section-specific estimate of severe injury crashes. The crash period used in ANRAM is 5 years.

Then, in the Crash Validation Module (CVM), the observed severe crash history for each section is used to supplement the estimated crash count from CPM. ANRAM uses the Empirical Bayes method, based on the Highway Safety Manual solution, to produce the final expected estimate of severe crashes per section, the ANRAM FSI crashes (FSI stands for fatal and serious injury). The Empirical Bayes method assigns low weight to the estimated value from CPM at locations with strong observed severe crash history. Where there are no severe crashes, CPM value is given a stronger weighting. This addition of observed severe crash data also accounts for road user-related risk. In many cases the gap between the observed and estimated severe crash counts is due to road user factors, such as lower speeds due to congestion, remoteness factors (low police enforcement, low crash reporting rates), or driver fatigue.

ANRAM processes these calculations for each of the six severe crash types: run-off-road, head-on, intersection, pedestrian, rear-end[2] and other.

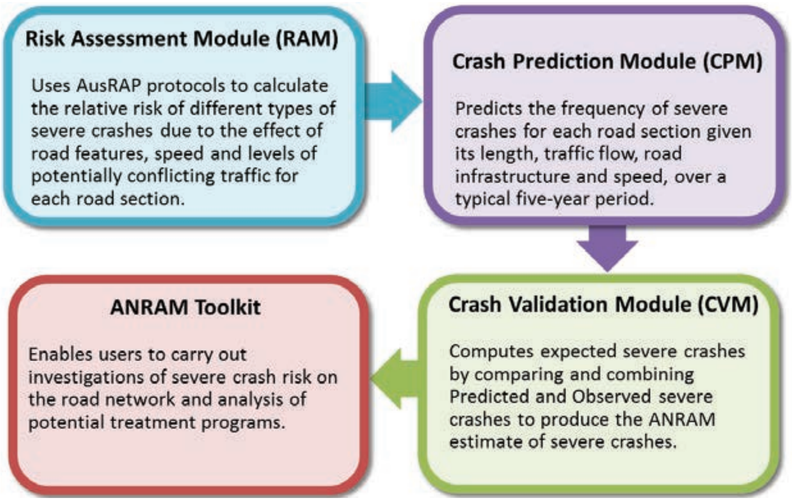

Fig. 2. ANRAM v1.0 process.

---

[2] Pedestrian and rear-end models have been provided in the v2 prototype, still under development.

ANRAM outputs a number of variables useful for monitoring of road safety performance at road network level. For example, road sections may be ranked on the basis of individual risk (ANRAM risk scores) representing the safety of road infrastructure and speed. They can also be ranked on the collective risk (ANRAM FSI crashes) which is more typically aligned with the conventional approach by road agencies, but is based on more statistically robust data, not subject to random variation in low severe crash counts. Using the estimate of ANRAM FSI crashes enable economic analysis of road trauma costs, and of any potential road safety benefits arising from road programs.

These processes and outputs lead the user to the ANRAM v1.0 Toolkit. It provides basic functionality to analyse the selected road network, discover which sections carry the highest risk of severe crashes, to identify the key road attributes associated with high risk of severe crashes. It enables targeted analysis of selected crash types, e.g. in preparation of a road safety program. Once sections are prioritised, the Toolkit helps the user to scope and cost alternative road safety program options. This is achieved by substituting high-risk road attribute categories with improved categories (e.g. improved intersection controls, road safety barriers instead of roadside hazards). ANRAM then calculates the hypothetical FSI injury crash counts for the improved road network. FSI crash reductions, and cost benefits are easily calculated by the Toolkit by automatically comparing the hypothetical improved road network with the baseline road network. ANRAM computes preliminary BCR which can be refined outside of the model using local economic parameters. Export functions are available at every step to enable advanced users to carry out more sophisticated analysis outside of ANRAM.

4. Applications of ANRAM

The typical users of ANRAM have been road agency road safety managers who use it to analyse road infrastructure issues, and develop and evaluate road safety improvement programs. Surprisingly, ANRAM has been also taken up in some jurisdictions by road asset managers keen to account for safety benefits of targeted road maintenance and rehabilitation programs.

Those focussed on road safety, have used ANRAM to develop programs ranging from Safe System transformation projects (i.e. major changes in road design seeking to minimise severe crashes), through incremental targeted improvements, to low-cost systemic improvements (e.g. improving road delineation across parts of the network).

One of the key features of ANRAM v1.0 Toolkit is the treatment selection flexibility, which is left entirely to the user. Road agencies can focus on selection of treatment types most viable on different parts of their road network, taking into account climate conditions, constructability and local product availability. This level of user input is useful given that most users are experienced road professionals, or are guided by such.

This in-built flexibility also makes it easier for road safety programs to be developed under different business rules applicable in each jurisdiction. This depth of approach ensures that crash risk-based road safety programs can be implemented as effectively as the current crash-based programs.

Further details of ANRAM v1.0 objectives, operation and outputs of interest to road agencies may be found in Jurewicz & Steinmetz (2014). ANRAM v1.0 is presented in the form of a Microsoft Excel 2010 application, but is in the process of being upgraded to a web-based v2 tool by the end of 2016.

User support is provided via the ANRAM Hub (ARRB 2014). The Hub includes the ANRAM User Manual, factsheets and instructions for preparing data, processing results, analysis of high-risk sections and initial evaluation of potential mass treatments and programs. ANRAM user training sessions are delivered from time to time to provide more in-depth skills for efficient handling of data preparation and analysis.

ANRAM v1.0 was trialled during 2014/2015 by all major Australian state jurisdictions, i.e. New South Wales, Victoria, Queensland, South Australia and Western Australia. Each jurisdiction pursues different priorities and funding programs under the National Road Safety Strategy to identify high-risk road sections and prioritise them for improvement. Thus each agency had a different approach to ANRAM implementation. These first stages of ANRAM implementation provide examples of how it may be applied by road agencies in the future. Several uses of ANRAM v1.0, based on the jurisdictional trials and suggestions, are presented below.

4.1. Business case for a themed mass-treatment program

This application of ANRAM builds a business case for a themed mass-treatment program where a road network is targeted for a retrofit with one type of treatment addressing a priority crash type. An example of this may be application of consistent curve delineation treatment schemes on lower order rural roads. A logical rule is applied in the Toolkit seeking high-risk curves to apply a treatment package of linemarking, signage and shoulder widening in certain conditions. The expected reduction in severe run-off-road crashes is then estimated and monetised to a net present benefit (NPV). ANRAM also provides an estimate of quantities of paint and signs used, hence costing can be developed, and then a BCR. This information can be used in preparation of business case for a road safety program targeting curve crashes.

4.2. Optimising a network-wide low-cost crash risk reduction program

A similar, but more evolved approach would involve full analysis of the baseline ANRAM risk scores across a given road network, e.g. high-volume rural and outer metropolitan highways. Such analysis may focus identifying and noting all road sections with high ANRAM risk scores. Such data can be easily mapped through a GIS platform (e.g. ArcView, QGIS, or InfoMap), where filters can applied to better understand which road attributes contribute to high risk. Sections with specific risk factors can be easily identified and 'treated' via. ANRAM Toolkit with hypothetical changes. This leads to development of a multi-layered program of treatments addressing all main outstanding safety issues across the road network. A BCR can be estimated at the program level.

A further step could involve exporting the ANRAM Toolkit results and re-prioritising the road sections according to the highest Predicted FSI crashes per section. Such program would produce a higher BCR.

This approach can be considered proactive, as it does not depend on past crash history of every treated location, but will estimate a program-level reduction in future crashes.

4.3. Prioritising treatments proposed by a route safety review

The aim of a route safety review is to assess an entire logical length of road focussing on high-frequency crash locations, engineering deficiencies, enforcement, signage, road user behaviour and speed limit issues along the route. A strong focus is placed on community consultation and site visits to draw information on local safety issues. Safer operation of the route is achieved through targeted low-cost engineering works such as signage and line marking, safety barriers, improving clear zones, changes in speed limits and fatigue management solutions. In most cases the scope and locations of works are identified by site inspections, analysis of crash data and community inputs.

ANRAM can be applied to evaluate the benefits of route safety review's diverse improvement packages using the Toolkit or the data replacement method. If the second approach is used, the input baseline data file is modified manually to represent the proposed treatments. This is then reprocessed in ANRAM. The Predicted FSI crashes from the treatment file are compared with the baseline Predicted FSI crashes. A percentage crash reduction can be calculated for each road section due to the treatments. This crash modification factor (CMF) is then applied to the baseline ANRAM FSI crash values to estimate the program crash savings. These steps are essentially the same as within the Toolkit and BCRs can be calculated for each section and the program as a whole outside of ANRAM. While this approach is more manual it allows a more flexible and refined evaluation of treatments than is currently available in the Toolkit.

ANRAM can also be used to develop and evaluate several alternative route safety review treatment package options (e.g. high-, median- and low-cost).

4.4. Estimating benefits of Safe System transformation projects

Many road agencies are moving towards piloting Safe System transformation projects. The concept involves a dramatic re-design of a priority route using Safe System infrastructure elements with a view to minimising death and serious injury. In the rural context, this means providing continuous roadside and median wire rope barriers, reducing driveway and minor intersection access and converting major intersections to roundabouts. In order to attract funding of such projects road agencies need to demonstrate strong reductions in fatal and serious injury crashes, and positive BCRs.

ANRAM can be used in this context as well. Typically, Safe System treatments are applied wherever feasible, regardless of past crash history or risk level. The key aspects of treatment selection is exclusion of locations where the treatments may already exist, or are not feasible, and generating quantities for project costing. The Toolkit may be used if the application logic is simple, up to three levels. Otherwise the data replacement method offers a much more flexible logic design. It is even possible to capture costs of changes which are consequential due to treatments, such as removal of trees close to the road to allow for barrier installation. Again, ANRAM FSI crash savings can be estimated, along with project costs and BCRs. In this application, ANRAM becomes a scoping as well as evaluation tool.

4.5. Estimating road safety benefits of asset management

ANRAM can be used to identify road sections and segments for site inspection of asset deterioration, e.g. those with poor pavement condition, delineation or narrow clear zones. Risk scores may be translated into inputs to asset management systems. If confirmed on-site, maintenance such as clearing of roadside regrowth or pavement resurfacing may be programmed.

Another example involves using high risk scores (e.g. due to tight road alignment, steep grade, or intersections) to increase asset maintenance priority on certain road segments. This use is supported by the notion that one of the key roles of road asset preservation is maintenance of public safety.

Either way, road improvements from maintenance works can be captured, and ANRAM FSI crash savings can be estimated. ANRAM can help to estimate additional monetary benefit from prioritised road maintenance activities which reduce severe crashes. Such information may be used to support the road maintenance funding consideration process.

4.6. Assessment of road design options

Assessment of road safety impacts of major transport infrastructure and urban planning projects can be carried out in ANRAM. Alignment and functional design options for new roads, bypasses or duplications can be compared using Predicted FSI crashes based on a future planning horizon traffic volumes. The assessment would be done in a similar way to existing roads, but rather than basing the input data on video, the users would assess design plans. The more advanced the design, the fewer assumptions would be needed, and the more realistic the FSI crash record estimate. Since no Observed FSI crashes are typically available for a new road, the safety comparison may be made using Predicted FSI crashes for different design options.

This technique can be used to refine a design to provide a Safe System road, i.e. one where FSI crashes have been minimised. The assessment can be used as part of the business case supporting a particular design option (e.g. to demonstrate FSI crash savings compared with the lowest-cost option).

4.7. Route selection or improvement (e.g. mining roads)

ANRAM can be used to assess and compare individual driver’s crash risk on alternative routes. This can be useful for logistics or mining companies seeking to minimise driver injury and lost productivity due to crashes. One example of application is selection of a haulage route from a mine to the port. It is possible to quantify the difference in safety levels of similar routes.

In some cases large companies fund road improvements in order to enable use of the shortest route. ANRAM can provide the necessary information to target such improvements on the basis of road safety and design.

5. Case study

One of the Australian road agencies applied ANRAM v1.0 to quantify road safety benefits of five route improvement options being considered for a major regional highway. The route was an important coastal undivided rural highway running through several regional centres and a number of minor towns. The improvement options considered in the business case included:

- A Safe System transformation project seeking to minimise fatal and serious injuries along the route. This option incorporated 2+1 median wire rope barrier treatments, continuous roadside wire rope barriers, rural roundabouts, partial access closures, pedestrian and speed management treatments in towns.
- Three intermediate options limiting the Safe System transformation to all high-risk sections, and then only to progressively shorter sections based on high FSI crash numbers and applying selective crash location treatments at other locations.
- A program of treatments at high crash locations only, focussed on sites with the highest BCR only (the traditional approach to road safety programs in that jurisdiction).

ANRAM was able to calculate the baseline Predicted FSI crashes along the route which correlated well with the Observed FSI crashes (i.e. crash history). Figure 3 shows the comparison between the Observed crashes and Predicted crashes along a section of the route. The 'observed' map on the left shows where crashes have clustered along the route (darker dots), while the 'predicted' map on the right shows that severe crash risk was actually spread more evenly. This observation is typical on rural roads where the probability of a severe crash occurring on a given 3 km road section over 5 years is small due to low traffic flow. When such probability is low, the locations of individual crashes may vary between one crash period and the next. Seeking to prioritise treatments among locations with few crashes may lead to odd results (scattered, discontinuous treatments). On the other hand, ANRAM FSI crash estimate, combining the predicted and observed values, was able to highlight where crash risk probability was elevated due to road infrastructure deficiencies and it did so more consistently than the historical crash record.

The conclusion from Figure 3 would be that the majority of the section would require a targeted treatment to address the elevated risk of future severe crashes, rather than only the two or three locations with higher concentration of crashes (typically 1–3). This way the probability of future reoccurrence of severe crashes could be minimised.

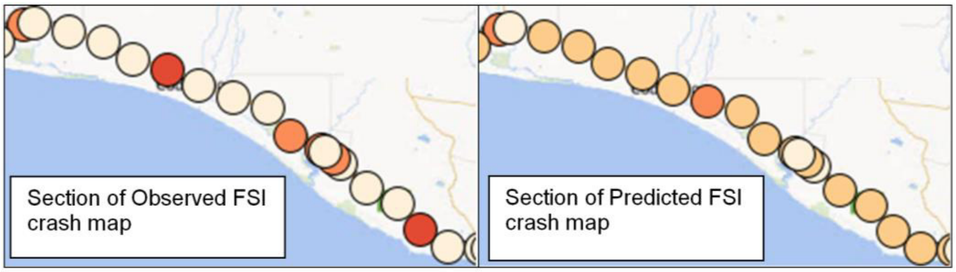

Fig. 3. Comparison between Observed and Predicted FSI crashes.

In this case, the road agency determined the treatments for each option based on a route safety review. Each option's treatments were coded into ANRAM using the data replacement method. This process reflected the proposed infrastructure and operating changes associated with each of the treatment options. The approach afforded greater flexibility and control over the localised changes than using the Toolkit.

The expected crash performance for each of the treatment options was estimated and compared with the baseline (untreated). As shown in Figure 4, the most substantial FSI crash savings were estimated for the Safe System transformation option, while the lowest savings were expected for the BCR-focussed option. ANRAM data allowed more in-depth analysis of crash savings, e.g. easy identification of the most promising links, i.e. those with the greatest expected future crash savings, or greatest reductions in individual driver risk.

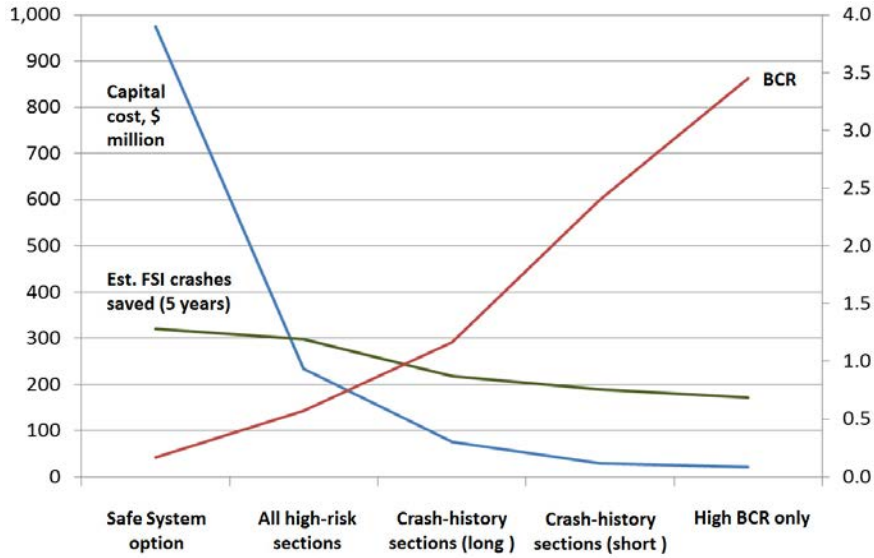

Fig. 4. Capital costs and FSI crashes saved vs. BCR for five route improvement options.

The preferred option was the middle option which returned a positive BCR and saved more FSI crashes than lesser options. This option included treatment of the significant crash locations as well as locations identified as having a high number of ANRAM FSI crashes, regardless of the recent crash history. This approach facilitated the prioritisation of high-risk sections for treatment prior to road trauma actually being realised.

6. The European context

There may be similar uses for a tool like ANRAM in the European context. Road safety performance functions are constantly being developed, refined and calibrated for different jurisdictions. The nature of statistical modelling limitations is that only a small number of model variables are ever going to be relevant in safety performance function. This is enough to identify high-risk sections, but not enough to drive detailed engineering treatment programs. The hybrid approach offered by Highway Safety Manual, and extended by iRAP and ANRAM, offers many more attributes which can be used in defining and refining road safety programs. European practice could build on the existing EuroRAP model. For example, EuroRAP data sets could be used to develop new statistical models and to provide better understanding how to best utilise the additional road attributes to drive road safety programs. Alternatively, entirely new road safety systems could be developed, e.g. sourcing information from existing macro and mezzo transport models. Development of an EU-wide system for modelling road safety performance and safety benefits of road improvement programs would provide a methodical platform assisting in prioritising of road infrastructure funding.

7. Current limitations and further development

ANRAM v1.0 was the output of the 2010–14 Austroads project and was produced as a Microsoft Excel tool. This allowed transparency of its inner structures and risk factors for analysis by road agency experts. A noted limitation of the Excel platform is the lack of intellectual property security. This limited the accessibility of the current ANRAM version to road agencies and created the need for strict version control. Austroads and its ANRAM governance partners iRAP, Australian Automobile Association and ARRB, have already committed to further development of the tool by moving it to a new software platform. It is going to be web-based software with close links with iRAP's ViDA. This means that new functionalities not available in Excel will be possible, e.g. mapping, processing of large data sets and innovative visual analysis of risk distributions and treatment benefits.

The current ANRAM development program includes prioritised functional and algorithm improvements to assist in nationwide road agency implementation. One of the improvements has been inclusion of pedestrians in ANRAM v2. Also, improvements to crash type models have been carried out, e.g. a separate rear-end crash model.

This stage of development is occurring in 2014–16 and the results are shared with the international iRAP community. The collaboration facilitates sharing of common input data sets, improved functionality and easier incorporation of new scientific knowledge.

ANRAM outputs have been satisfactorily evaluated through the jurisdictional trials. The risk ranking of road sections has compared well with iRAP results. ANRAM FSI crashes correlate well with severe crash history at the road network level. At the local level, FSI crashes are often distributed with a high degree of randomness, hence the correlation with mathematical predictions of ANRAM can be low. One aspect which may improve ANRAM's accounting for crash risk is inclusion of road user and vehicle fleet risk factors (e.g. fatigue, Police enforcement levels, fleet age, percentage of heavy vehicles). This is to be considered in a future research and development phase.

Another point of discussion is using ANRAM as a safety module in an overarching transport planning platform, together with other models for estimating traffic flow, travel time, and public transport priority. Such a platform would provide a rich decision support tool for transport departments to monitor and adjust road network parameters for safe and full integration of road transport.

One of the foreseeable side benefits of ANRAM is the growing data set of road attributes, traffic volumes and FSI crash data. This opportunity is already generating studies seeking to refine our understanding of the links between road design and safety, and consequently of road design guidelines.

8. Conclusion

This paper presented the key aspects of ANRAM and has shown how it can be used to drive road safety infrastructure program development. It presented ANRAM's background as a tool for identification and prioritising of road sections with high risk of severe crashes. The paper showed how hybrid risk assessment and crash prediction methodology are applied to estimate individual and collective severe crash risk. A number of innovative uses being trialled by Australian road agencies were described, plus several potential future uses. A case study showed how a jurisdiction applied ANRAM to select an economically acceptable yet proactive route improvement option. Future directions of ANRAM development were also noted highlighting some of the improvements. Suggested points of similar practice in Europe were briefly presented for further consideration.

References

AASHTO 2010, Highway safety manual, 1st edn, American Association of State Highway and Transportation Officials, Washington, DC, USA.

ARRB 2015, ANRAM Hub, ARRB Group Ltd, Vermont South, Vic, viewed 17/09/2015 <www.arrb.com.au/anram>

Australian Institute of Health and Welfare, 2015, Trends in hospitalised injury, Australia 1999-00 to 2012-13, Injury Research Statistics Series Number 95, Australian Institute of Health and Welfare, Canberra, ACT, Australia.

Australian Transport Council 2011, National road safety strategy 2011–2020, ATC, Canberra, ACT, Australia.

iRAP 2015, Methodology, fact sheets, iRAP, London, UK, viewed 17/09/2015 < http://irap.org/en/about-irap-3/methodology>

Jurewicz, C. & Steinmetz, L. 2014, Australian National Risk Assessment Model, AP-R451-1, Austroads, Sydney, NSW.

Lydon, M., Woolley, J., Small M., Harrison J., Bailey T. and D. Searson 2015, Review of the National Road Safety Strategy, Austroads AP-R477-15, Sydney, New South Wales, Australia.