Journey Optimisation by Safest Route

Hamish Kingsbury[a], Dale Harris[a] and Paul Durdin[a]

[a]Abley Transportation Consultants, Christchurch New Zealand

Abstract

Efficient routing of private and commercial vehicles is valued for saving travel time and reducing vehicle running costs. Employers must also consider the safety of their staff while on the road, and many implement policies that support safe driver behaviours and the use of safe vehicles. To date there has been little research into the integration of both routing and safety – allowing road users to choose the safest, in addition to the shortest or quickest routes.

This paper outlines a research project, undertaken as part of a Callaghan Innovation Student Experience Grant, which investigated how road risk assessment methodologies can be incorporated into a vehicle routing model. Two methodologies for calculating, predicting and quantifying crashes and road safety were examined and tested for the Greater Auckland Region: predictive crash models from the NZ Transport Agency's Economic Evaluation Manual, and reactive crash models based on the Urban KiwiRAP risk assessment methodology.

The project was developed using Geographical Information Systems (GIS), specifically ArcGIS Network Analyst. The output of the trial was an interactive website that allows for users to choose and weight three routing variables: travel time, distance and safety. The route that best meets the chosen priorities is then calculated and displayed on screen.

This project demonstrates potential for safety-based vehicle routing and supports a safe system approach to managing the road safety risk associated with work-related driving. The next step is to explore the commercial opportunities from this research, including partnerships with interested public bodies and commercial vehicle routing services.

Introduction

Vehicle routing is a complex process that is used by businesses and individuals to optimise travel times and reduce vehicle running costs. Optimal vehicle routing is typically undertaken using applications which apply variables such as distance and historic and real-time travel time data to calculate the most efficient route between a defined origin and destination. Currently there are no known vehicle routing services that explicitly incorporate safety variables into vehicle routing.

There is a broad application for routing based on safety. Many companies require routing as part of their day-to-day business operations. With increasing dependence on fast, reliable and safe transport, the idea of taking safety into account would be of interest to companies looking to reduce risk, whilst minimising distance and time costs. Industries and businesses that are reliant on driving (such as logistics and distribution, tradespeople and taxi drivers) could all benefit from a routing system designed to inform them about the relative risk of different route options whilst still supporting efficient business practices. By incorporating safety into distance and time based route calculations, employers can also meet their workplace health and safety obligations.

As part of a Callaghan Innovation Student Experience Grant[1], a research project was completed that explored the feasibility of incorporating safety data into a vehicle routing network. The primary

[1] Callaghan Innovation is a New Zealand Crown Entity established to support the commercialisation of innovation in New Zealand businesses. The Callaghan Innovation Student Experience Grant is a paid R&D internship that provides work experience for students.

output of this research is an interactive website that demonstrates the feasibility of integrating safety metrics into vehicle routing. The website allows users to specify how they would like their route to be calculated by rating the relative importance of safety, distance and travel time. The result is then displayed, along with the shortest and fastest routes; allowing for a visual comparison of options. The methods used in the application have the ability to be scaled and implemented into existing routing applications.

The research also supports the safe system philosophy and the New Zealand's Safer Journeys vision for a 'safe road network increasingly free of death and serious injury' (Ministry of Transport, 2010). The application raises awareness of road safety and empowers road users to make smarter decisions about how they use the road network.

Models of road risk

To calculate the relative risk of travelling a particular route, this risk must be quantified and aggregated across every section of road travelled. The research project investigated two methods of quantifying road safety risk. The first method is a predictive risk assessment from the Economic Evaluation Manual (EEM), which includes procedures to calculate the safety benefits and costs of transport projects (New Zealand Transport Agency, 2013). This risk assessment does not take into account historic crash data, but instead relies on regression algorithms that explain crash performance based on physical and operational variables, such as intersection form and traffic volumes. Whilst the algorithms have been developed by correlating specific features and characteristics with known crash performance, the application of the EEM procedure generates expected injury crash rates that are predictive in nature.

The second method tested is the Urban KiwiRAP methodology, which relies on crash history to predict the likelihood of future deaths and serious injuries if current crash trends continue (Brodie et al., 2013). Urban KiwiRAP calculates two risk metrics that can be used to quantify road safety risk:

- **Collective Risk** is measured as the estimated number of deaths and serious injuries based on severity indices associated with historic crash data.
- **Personal Risk** is the risk of death or serious injuries per 100 million vehicle kilometres travelled.

Urban KiwiRAP is a reactive approach to risk assessment. Waibl, Tate, & Brodie (2012) discuss the shortfalls of such a method. For this research, the Personal Risk metric was used as it provides a risk relative to an individual and not the absolute, or Collective Risk of each route.

Table 1 outlines the two methods tested, their required inputs and calculations. It shows how the two methods vary and indicates why there may be differences in the results.

Table 1. Outline of the inputs and calculations required for each of the methods.

Method	Inputs	Calculation
Economic Evaluation Manual	• Annual average daily traffic (AADT) • Length of the link • Two model parameters based on the road type	Using regression, a formula is populated with the appropriate values and the resulting metric is calculated.
Urban KiwiRAP	• Number of lanes • Annual average daily traffic (AADT) • Number of injury crashes (over five years) • Speed environment (urban/rural)	A model assigns crashes to links and based on a range of input criteria and the type of crash, calculate the Collective and

	• Road hierarchy	Personal Risks.

KiwiRAP star rating was considered as an alternative method for quantifying road safety risk along corridors, however at the time of the research, star rating had only been undertaken for the New Zealand State Highway network. While further star rating assessment is currently being undertaken for selected roads in some of New Zealand's main cities, the lack of risk assessment coverage makes it difficult to quantify risk across an entire road network.

Methodology

A Geographical Information System (GIS), ArcGIS 10.2, was used to view, manage and work with the data. The GIS contains a range of tools that enabled analysis and development of the spatial data. Once the necessary data had been acquired, development of a vehicle routing network and comparison of the two safety metrics was undertaken. The project was concluded with the development of an interactive website.

The Auckland region New Zealand was used as the study area for this project. Auckland was one of the first regions in New Zealand to have Urban KiwiRAP safety metrics calculated (Figure 1) and provided a mix of urban and rural road environments to test the routing model. There was also sufficient suitable data available for calculating the metrics using the EEM methods as well as a complete set of road centrelines.

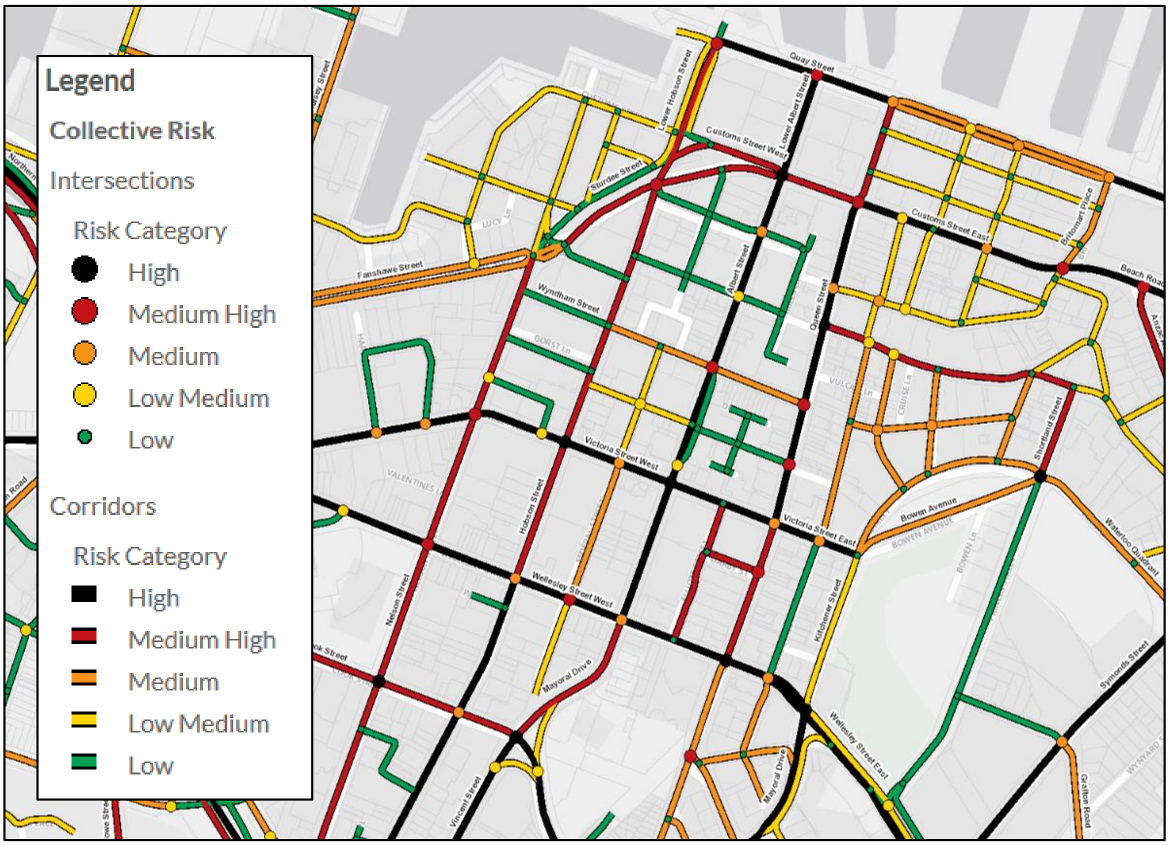


Figure 1. Map showing Urban KiwiRAP Collective Risk metric for central Auckland.

Data

The road centreline used to create the vehicle routing network was taken from Urban KiwiRAP. This data contained Urban KiwiRAP safety metrics, the annual average daily traffic (AADT) count and speed environments. These values were required by the models in the EEM to derive safety metrics.

Further data was added used to refine the vehicle routing network, such as information on the direction of flow along roads which was required to produce a more accurate network. Often this could be determined by viewing online maps and imagery but in some cases the information had to be taken from other data sources.

Network and routing development

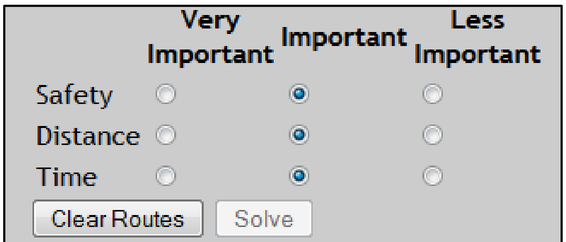
A vehicle routing network contains interconnected links and nodes which represent a collection of roads. Each link contains attributes (such as hierarchies and travel directions) and an impedance value which when each section is traversed, accumulates. The GIS uses Djkstra's algorithm (ESRI, 2014) which aims to solve the network by accumulating the lowest impedance. Depending on the impedance value, different routes between the same points can be created.

Utilising GIS software, a vehicle routing network was created. Each link of the routing network was assigned a value of safety risk, both a Personal Risk value (from Urban KiwiRAP), and EEM predictive risk value. The times taken to traverse each link on the network were calculated using the posted speed limit and the length of the segment.

Using GIS network analysis and routing algorithms, the network was used to identify the safest (lowest safety risk), shortest (shortest distance) or fastest (shortest time) route between two or more locations. Testing of the methodology found that in some instances the safest route was significantly longer than both the shortest and fastest route, and hence would be considered impractical from a road users perspective. Hierarchies and a 'baseline' level of risk were introduced to resolve this problem.

The initial scope of the project involved allowing a user to identify an acceptable level of risk, based on how much further/longer they would be willing to travel compared to the shortest or fastest route. For example, if the fastest route between two locations is calculated as 10 minutes, and the user is willing to travel an extra 10% longer for a safer route, the routing application would then assess the safest route that would take less than 11 minutes. This problem is a variation on the "Resource Constrained Shortest Path Problem" (Irnich & Desaulniers, 2005) which was unable to be solved by the GIS. For this reason, an alternative (and simpler) method was developed using weightings instead.

The weighting system allows users to choose their relative preference for safety, distance and travel time using a matrix (Figure 2). The matrix takes the users input and calculates an impedance value based on what was chosen. If safety, distance and time were all given the same level of importance, these values will be normalised and then combined with each having a weighting of 33.3%. If the user states that safety is very important and distance and time are less important then the weighting returned should be the normalised safety value. However, as noted above, testing found that this weighting would often result in situations where a user would take a convoluted route by only travelling down low hierarchy roads with no respect to either time or distance. To resolve this, the



weighting when safety is very important is capped at 80% safety and 20% distance.

Figure 2. Safety, distance and time user preference matrix

Comparison of safety risk metrics

The EEM and Urban KiwiRAP measures of road safety risk were compared throughout the network and routing development process. During this process it was found that Urban KiwiRAP provided the most reliable predictor of road safety risk for routing purposes. Figure 3 displays some of the

differences between the two risk metrics.

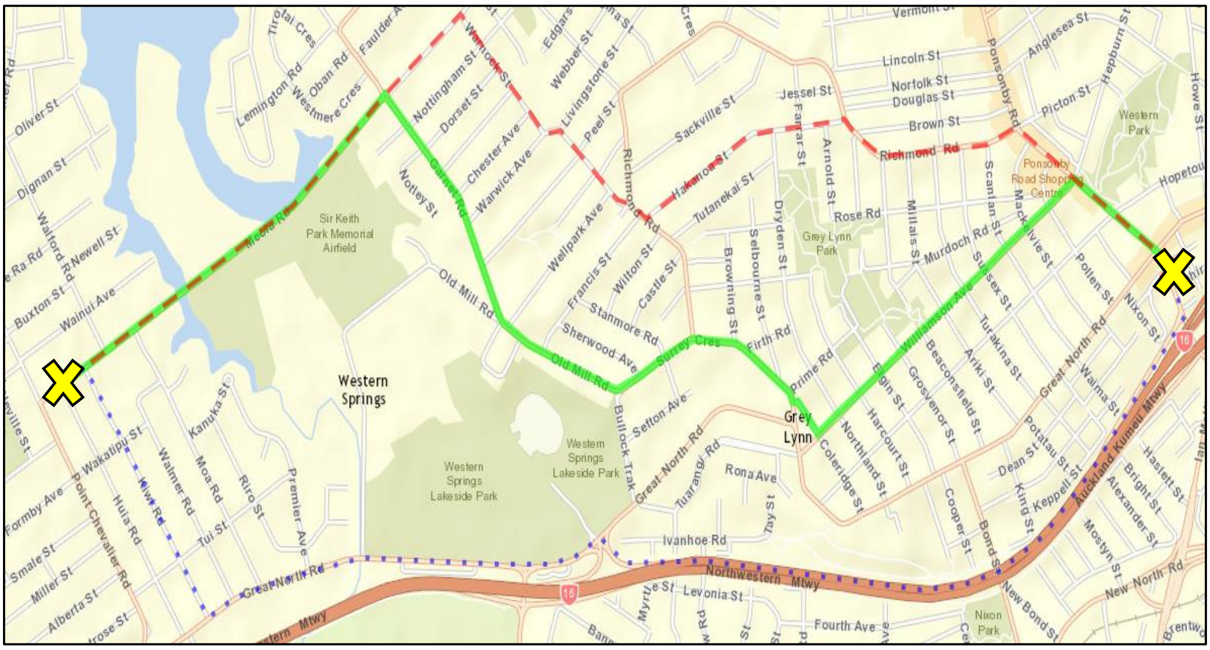
Figure 3. Comparison of EEM (left) and Urban KiwiRAP (right) risk centreline

Through testing it was evident that Urban KiwiRAP was the preferable choice for determining the risk of roads. It was noticed that the EEM risk metric tended to route onto low volume local roads because fewer crashes would be expected to occur in these environments; however, these are often impractical for routing purposes. The EEM models avoided high volume roads (such as motorways) even when there were comparatively fewer crashes, which is not unexpected as the models return average values for safety performance based on the sample of data from which they were created.

The Personal Risk metric from Urban KiwiRAP contrasted the results from the EEM. It analysed many roads with a high AADT as low risk due to them having a relatively low number of crashes for the amount of road use. Some lower volume roads with a low number of crashes were classed as higher risk as the ratio of crashes to vehicle volume was greater.

Web interface

A website was developed to interactively allow users to identify, process and display routes, and to enable users to graphically compare the safest, shortest and fastest routes (Figure 4). Accompanying



the route are some complimentary comparison statistics quantifying the variations between the routes (Figure 5). The statistics provided allows the user to make an educated decision as to which route is the most suitable for them.

Figure 4. Sample output from the routing website displaying the shortest (dashed red), quickest (dotted blue) against the preferred route (solid green).

Figure 5. Sample output displaying the difference between the three routes.

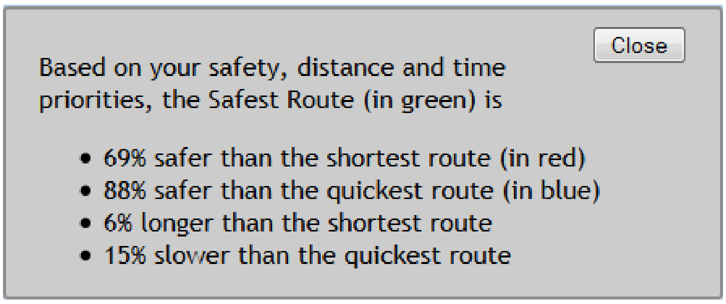
Discussion

The research project demonstrated that integrating safety metrics into a vehicle routing network is feasible.

Suitability of metrics

Road safety risk quantified using the Urban KiwiRAP Personal Risk metric was determined to be a more suitable risk metric than EEM crash prediction models for the purpose of developing a safety routing network methodology. Personal Risk provides a risk value at an individual level and can be accumulated to calculate total Personal Risk along the length of the route.

Safety is often 'assumed to be inherent in design policies and practices' (Federal Highway Administration). While this may be true, some roads exhibit better safety performance than others. The International Road Assessment Programme (iRAP) defines three RAP protocols; namely risk



mapping, Star Rating and performance tracking (Brodie, et al., 2015). The Urban KiwiRAP metrics used in this research are derived from the risk mapping protocol and therefore are removed from specific design features of intersections and corridors. Star Rating in New Zealand is presently limited to the high-speed State Highway network. Star Rating is an assessment of the engineering features of a road that contribute to safety outcomes, it does not look at crash history. Roads with exceptional safety features are assigned a 5 Star Rating whereas roads with no or minimal safety features are assigned a 1 Star Rating. Information is currently being collected in urban environments in New Zealand to develop an Urban KiwiRAP Star Rating. When this information becomes available, it is possible that this proactive risk metric may become a better metric for any safety routing calculations than reliance on historic crash performance.

Past research outlined by Navin et al. (1996) explores a number of methods that can be used to calculate and derive road safety. However it appears that these models provide a global safety metric, not something that can be applied to individual roads and therefore be used for routing.

Work by Usman et al. (2010) is promising as they explore how the Negative Binomial model can be applied to road safety. They state that this has 'been found to be the most suitable distribution structure[s] for road accident frequency'. The paper explores how winter road maintenance in Canada can be quantified in terms of safety benefit. Using exploratory data analysis, a range of factors/variables were assessed to determine whether they were statistically significant at the $p<0.05$ level in determining the frequency of accidents. A similar approach would prove beneficial to determining and deriving road safety in New Zealand.

As mentioned, investigation into methods of quantifying road safety that have a greater coverage is needed. This was one of the limitations of this project as 48% of all roads in the study area of Auckland did not have enough historic crash data to successfully derive crash metrics. This may have skewed the results but there was no suitable or comparative safety metrics available.

There needs to be further research into how the EEM and Urban KiwiRAP derive safety. They are both New Zealand specific applications and further development will improve the usability and accuracy of the two methods. Urban KiwiRAP relies on crashes taking place in order to derive and calculate safety metrics (Waibl et al., 2012). Over time, as roads become safer under the Safer Journeys Strategy, it will become increasingly difficult for Urban KiwiRAP to derive safety metrics for all but New Zealand's busiest roads.

Routing development

There are a number of improvements to the underlying routable network that would provide more accurate and reliable outputs. More complete data on the road network as well as investigation into the implementation of the Resource Constrained Shortest Path Problem would benefit further development of this research.

The GIS-based vehicle routing network used in this research was very basic. The centreline used contained only some of the necessary data to develop a robust vehicle routing network. More information such as turn restrictions, access restrictions and travel times are required to develop a more accurate vehicle routing network. Typically, this data is only available through commercial data sets.

This project aimed to be a 'proof-of-concept', thus it is not currently suitable for application. The limitation of this vehicle routing network has been identified and would require further development before becoming usable. It is unknown if data (such as safety) would be able to be added to a commercial dataset. Therefore it would be an option to collaborate and work with a company providing vehicle routing networks. Another approach would be to explore Open Street Map (OSM). OSM uses Volunteered Geographic Information (VGI) to gather and build data.

The method of weighting used constrains the ability for a user to specify quantifiable differences, they are only able to specify variations relatively, not absolutely. To implement the Resource Constrained Shortest Path Problem significant resources would need to be used to develop and implement a tool. This could be done in a number ways, the most useful would be to develop a plugin that would work with ArcGIS, the platform used to develop this project. If a tool was developed that could solve the Resource Constrained Shortest Path Problem this would expand the ability for a user to further control and manipulate the factors that calculate their route.

The methodology applied can easily be altered and scaled to use on different datasets and locations. Any changes to algorithms used simply need to be re-entered and the model re-run if anything changes. The flexibility allows for simple and easy maintenance as well as scalability to incorporate larger areas or more complex networks.

Conclusion

This project has successfully managed to prove that routing using safety metrics is feasible. By testing and comparing the Economic Evaluation Manual and Urban KiwiRAP it was determined that the Personal Risk metric from Urban KiwiRAP was suitable for this application. However there were a number of limitations to this dataset as it does not provide a complete coverage of all the roads in Auckland.

One of the aims for this project was to allow for the user to choose how the route would be calculated in terms of safety, distance and time. As an alternative to the Resource Constrained Shortest Path Problem, a method of weighting and associated matrix was developed that fulfilled this requirement. However it does not provide the full flexibility that would be available by ‘solving’ the Resource Constrained Shortest Path Problem.

Whilst the research has satisfied its original objective, that is, demonstrating that combining safety metrics with a vehicle routing network is feasible, there are a number of areas for improving and refining the safety routing process. Currently there are only a few methods of quantifying and deriving safety for roads. The suitability of using safety data in routing networks has had little study. The study area needs to be expanded to further develop and refine the outcome.

References

Arsanjani, J., Barron, C., Bakillah, M., & Helbich, M. (2013). *Assessing the Quality of OpenStreetMap Contributors together with their Contributions.* Leuven.

Brodie, C., Tate, F., Minnema, R., Comber, R., Durdin, P., Gardener, R., & Waibl, G. (2015). *Urban KiwiRAP Identifying Road Safety Risk on New Zealand's Urban Roads.*

Comber, A., See, L., Fritz, S., Van der Velde, M., Perger, C., & Foody, G. (2013). Using control data to determine the reliability of volunteered geographic information about land cover. *International Journal of Applied Earth Observation and Geoinformation*.

ESRI. (2014, July 2). *Algorithms used by the ArcGIS Network Analyst extension*. Retrieved July 1, 2015, from ArcGIS Resources: http://resources.arcgis.com/en/help/main/10.1/index.html#//004700000053000000

Federal Highway Administration. (n.d.). *Crash Modification Factors in Practice, Quantifying Safety in the Road Safety Audit Process.*

Irnich, S., & Desaulniers, G. (2005). *Shortest Path Problems with Resource Constraints.*

Ministry of Transport. (2010). *Safer Journeys - New Zealand's Road Safety Strategy 2010-2020.* Retrieved from http://www.saferjourneys.govt.nz/assets/Uploads/SaferJourneyStrategy.pdf

Mooney, P., Corcoran, P., & Winstanley, A. C. (2010). *Towards Quality Metrics for OpenStreetMap.* San Jose.

Navin, F. P., Bergan, A., & Zhang, G. (1996). Road Safety Model: Some Fundamental Ideas. *Transportation Research Record: Journal of the Transportation Research Board*. doi:dx.doi.org/10.3141/1563-07

New Zealand Transport Agency. (2013). *Economic Evaluation Manual.* Retrieved from http://nzta.govt.nz/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual.pdf

Usman, T., Fu, L., & Miranda-Moreno, L. F. (2010). Quantifying safety benefit of winter road maintenance: Accident frequency modeling. *Accident Analysis and Prevention*.

Waibl, G., Tate, D., & Brodie, C. (2012). *The development of a proactive road safety assessment tool - KiwiRAP.*