Incorporating Road Safety into Vehicle Routing

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ABSTRACT

The Safer Journeys Strategy developed by the National Road Safety Committee takes a four pillar approach to safety. This paper uses those ideas to explore how existing road safety methods can be used in vehicle routing applications.

Two existing methodologies for quantifying crashes on routes were examined. Both of these methods were tested to determine which was most suitable for utilization in an interactive routing web application. The testing and development was done using the geospatial software, ArcGIS. One of the tools used was the Network Analyst Tool (NAT). This provided the functionality for vehicle navigation and routing.

The final outcome of this project is a website that allows users to specify how important they find safety in comparison to distance and time, and generates a route based on those choices. Currently, the website only operates in the Greater Auckland Region (New Zealand), but the ground work is there for development in other regions.

The accuracy of this project was limited by safety data typically only being available for arterial roads. The work identified the need for a broader safety metric that can be applied to all roads.

This project was completed as part of a Callaghan Innovation Research Grant over the 2014/15 university holidays.

INTRODUCTION

Vehicle routing is an inherently complex process. Businesses and individuals use various existing applications, such as RouteSmart, Paragon and GoogleMaps, to reduce travel times and vehicle running costs (through reduction in travel distances). These typically use historic and real-time traffic and travel data, distances and speed limits to optimise the user's route. Currently there are no routing applications that explicitly state that they use road safety metrics to calculate a user's route.

Safety based routing has a wide variety of applications. Many companies rely on efficient routing to provide customers with reliable and fast transport logistic solutions. This paper explores how road safety metrics can be incorporated into a vehicle routing network (VRN) whilst still taking into account travel time and distance.

The research project behind this paper was completed as part of a Callaghan Innovation Student Experience Grant[1]. The goal of the research was to explore the feasibility of using road safety data to determine optimally safe routes for vehicles. The deliverable for this project was an interactive website[2] that demonstrates how road safety can be incorporated into a VRN. The website allows for a user to specify the relative importance of safety, distance and travel time. It then calculates an optimised route between locations within Auckland based on these specifications.

This project aligns itself with the vision of the Ministry of Transports Safer Journeys Strategy to provide a 'safe road network increasingly free of death and serious injury' (Ministry of Transport, 2010).The website allows for users to make smarter decisions about how they travel and raises the awareness and importance of road safety.

[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.

[2] The website can be viewed here: dev2.interpret.co.nz/safetyrouting. Please note it is a demonstration and in its current state not intended as a replacement for other routing services. The area is limited to Greater Auckland.

Geographic Information System

This project made use of a Geographic Information System (GIS). The GIS used, ESRIs ArcGIS 10.2, enabled the viewing, management and manipulation of the necessary data. ArcGIS also contains a range of tools that allowed for the analysis of safety data and the development of the VRN. The extension, Network Analysis, was used to assist in the development of a satisfactory VRN.

Vehicle Routing Network

A vehicle routing network (VRN) is a computer based representation of a real-world road network. At its most basic, a VRN is represented as a connected graph. Vertices (points) represent intersections and edges (lines) represent the roads connecting these intersections. In the simplest of VRNs each edge is weighted according to the length of the edge, this is known as an impedance.

To traverse a graph like shown in Figure 1, an algorithm is used to calculate the lowest cost route (lowest sum of impedances) between the specified start and end vertices (Laporte, 1992). Often Dijkstra's algorithm is used to solve such problems although others do exist (Eklund, et al., 1996). Complexity in a VRN begins when variables describing the real world road environment are introduced. Parameters such as one-way data, turn restrictions and hierarchies all add levels of complexity to the VRN. This results in the relatively simple Dijkstra's algorithm no longer being able to solve a route on such a VRN. Applications such as Network Analyst for ArcGIS use a variation on Dijkstra's algorithm to solve routes on these more complex VRNs (Environmental Systems Research Institute , 2010).

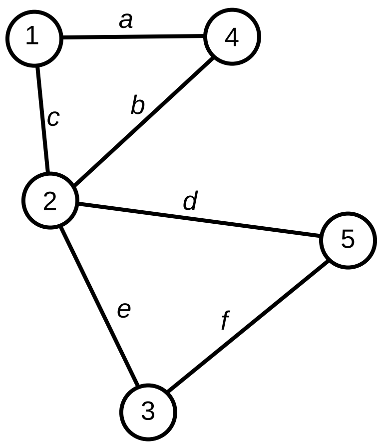

Figure 1. Example of a weighted graph. The numbers indicate vertices and the letters represent impedances. To get from 1 to 4 you sum up the weightings of each line traversed. In this example you could either sum *c* and b or use *a*. You would then use the lowest total value of those two paths. The impedance can be any value that will limit traversal, such as distance, time or safety.

Safety Metrics

Two methods of determining road safety were investigated in this project. They offered contrasting methods of determining the overall safety of sections of roads. The first method uses predictive models from the Economic Evaluation Manual (EEM) (New Zealand Transport Agency, 2013). These models provide estimates on the safety of road sections using physical and operational variables, such as intersection form and traffic volumes. The models are based on regression algorithms that correlate specific road features and characteristics with known crash performance indices.

The second method tested was Urban KiwiRAP. These rely on historic crash history to predict the likelihood of crashes provided that the current crash trends continue (Brodie, et al., 2015). Within Urban KiwiRAP there are two risk metrics:

- **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.

Both these metrics provide reactive approaches to safety. As identified by Waibl, Tate, & Brodie (2012) Personal and Collective Risks rely 'on crashes occurring and people being killed or injured. [Therefore] This reactive approach to safety prompts public responses such as "do we have to wait until someone is killed before something is done"'.

Within this project, the Personal Risk metric was used as it provides a risk value relative to an individual as opposed to the overall risk of the road corridor (Collective Risk). Table 1 outlines both the EEM and KiwiRAP methodologies and shows how they vary and why differences in the calculated safety metric may occur.

A third method of road safety was considered. The KiwiRAP Star Rating methodology was looked at but due to its limited coverage (only data for State Highways above 50km/hr was available) it was not used. As the coverage increases, this method has the possibility to be used in subsequent

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) • Road hierarchy	A model assigns crashes to links and based on a range of input criteria and the type of crash, calculate the Collective and Personal Risks.

versions of incorporating road safety into a VRN.

Table 1. Inputs and calculations required for each of the methods.

Glossary of Acronyms

Acronym	**Phrase**
ESRI	Environmental Research Systems Institute
NAT	Network Analyst Tool
VRN	Vehicle Routing Network
GIS	Geographical Information System
EEM	Economic Evaluation Manual
AADT	Annual Average Daily Traffic
RCSPP	Resource Constrained Shortest Path Problem
API	Application Program Interface
iRAP	International Road Assessment Program
OSM	Open Street Map

VGI	Volunteered Geographic Information

METHODS

The Greater Auckland region was used as the study area for this project. Auckland was one of the first regions in New Zealand to have the Urban KiwiRAP safety metrics calculated (Figure 2). The region also provided a range of varying road types allowing for comprehensive testing of the final result. Data needed for the EEM metrics was also readily available for the Greater Auckland Region.

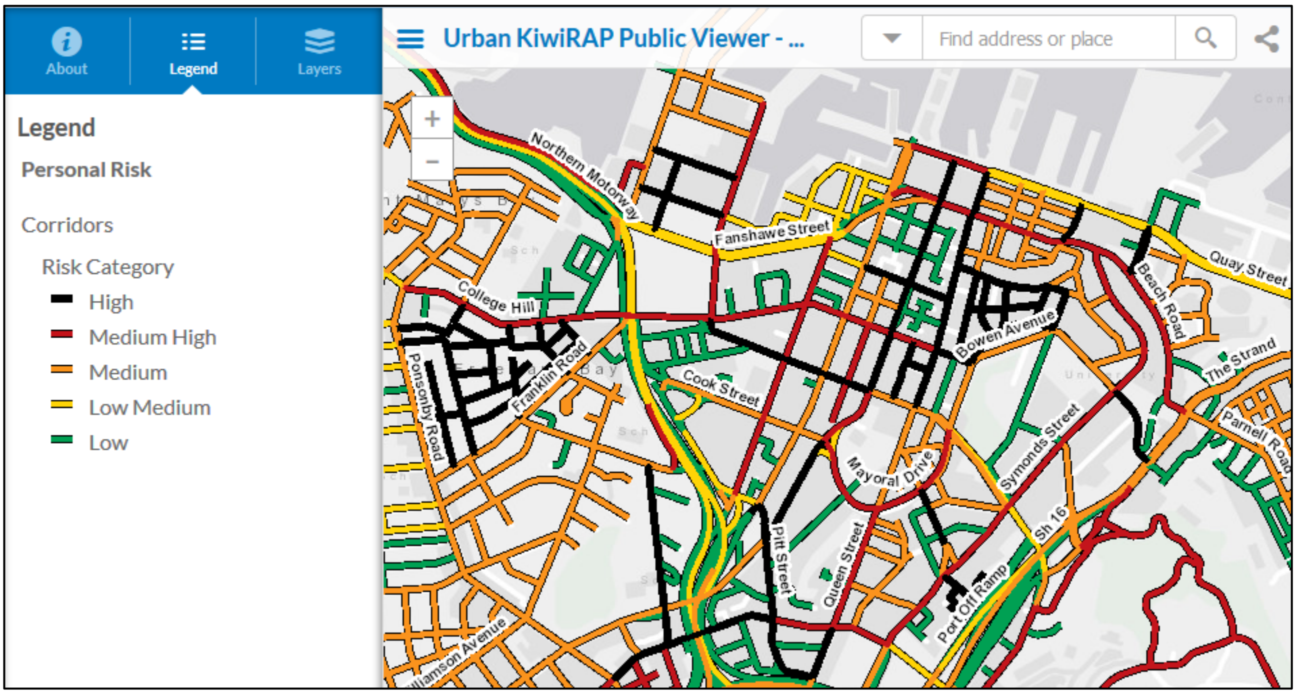

Figure 2. Example of Urban KiwiRAP safety metrics.

Data

The majority of the data used for this project was taken from Urban KiwiRAP. The geometry (lines representing roads) were sufficient to create a topologically correct VRN. Satellite and vehicle based images (Google Maps and Google Street View) were used to further refine and improve the network. This information provided flow directions and turn restrictions which were used to ensure the VRN represented the real-world scenario as accurately as possible.

The Urban KiwiRAP data contained both the Personal and Collective risk metrics as well as speed environments, annual average daily traffic (AADT) count, road hierarchies and intersection types. These values were used in the EEM models to derive crash and safety data.

Vehicle Routing Network Development

ArcGIS Network Analyst was used to create a VRN for the Auckland region. The basic VRN was able to produce routes that would satisfy the users request for either the shortest or fastest route. Both the Personal Risk from Urban KiwiRAP and the metrics calculated from the EEM were introduced into the VRN. This allowed for a safest route to be calculated.

Throughout the development of the VRN each of the safety metrics were evaluated. The final decision on which method of quantifying risk was made after the VRN was fully developed.

Whilst testing the two safety metrics it was noticed that often the safest routes would dog-leg and take convoluted, time consuming routes. To reduce the likelihood of this occurring, hierarchies and a baseline risk were implemented to resolve this problem. The hierarchies used were taken from Urban KiwiRAP and were classified based on the road importance (Table 2).

When testing the Urban KiwiRAP based VRN, it was noted that nearly half of all roads (48%, mainly local roads) didn't have sufficient injury crashes to meet the criteria (four or more injury crashes in the past five years) to calculate an Urban KiwiRAP Personal Risk. This results in a Personal Risk of zero. Therefore, when calculating a route, Network Analyst was able to traverse these sections of road without increasing the overall risk value. This resulted in excessively long routes where the route would aimlessly wander through streets with zero risk. To overcome this, a baseline Personal Risk value of 0.0001 was introduced. This problem did not affect the EEM metrics as every road had the necessary data to derive a safety metric.

Road Classification	Hierarchy (lower number, more important)
Motorway	1
Strategic Arterial	1
Primary Arterial	2
Secondary Arterial	3
Collector	4
Local	5

Table 2. Road Classification Hierarchies.

Developing a method of Weighting

For this project it was important for a user to be able to specify how much time/distance (as a percentage) they were willing to sacrifice in order to find a safer route i.e. the user is willing to travel 10% further to find a safer route. This problem is a subset of the Resource Constrained Shortest Path Problem (RCSPP (Irnich & Desaulniers, 2005)). The RCSPP is when an upper limit is placed on a variable that is not the (main) impedance value. A route is then solved that does not exceed the specified variable but does satisfy the specified impedance. An example is a backpacker travelling around the country. They want to find the fastest route between two locations that does not exceed their budget.

ArcGIS and Network Analyst cannot natively solve the RCSPP[3]. Therefore an alternative solution had to be devised. A system of weighting was developed that allows for a user to specify, relatively, how important safety, distance and time are to them. Using a matrix (Figure 3) users are able to specify the importance of each criteria.

To ensure that the weightings were fairly calculated, each criteria was normalised on a scale of 0-1. When each of the criteria is given the same importance, each value would have a weighting of 33.3%. When calculating the route, the impedance value for the VRN was based on this matrix. See Table 3 for some of the possible combinations and their associated weighting.

Note how when safety is selected as very important and distance and time are less important that the weighting is not 100% for safety. It was noticed during testing that if a 100% weighting for safety was used then the route produced would often choose inappropriate routes to avoid risky sections of road. This problem was not fixed by the introduction of a minimum safety rating. Therefore the highest safety weighting was capped at 80% safety and 20% distance (Table 3).

[3] A custom route solving extension can be developed using ArcObjects. This was out of scope for the project.

This results in a sufficient balance between the safest route and the other weightings. This combination was further tested to ensure that it provided a suitable balance.

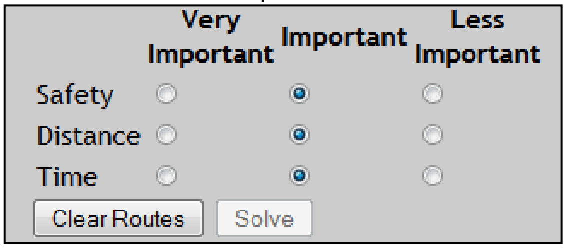

Figure 3. The matrix used to specify the relative importance of safety, distance and time.

Safety Importance	Distance Importance	Time Importance	Safety Weighting	Distance Weighting	Time Weighting
Important	Important	Important	33.33%	33.33%	33.33%
Very	Less	Important	66.66%	0%	33.33%
Very	Less	Very	50%	0%	50%
Important	Important	Less	40%	40%	20%
Important	Very	Important	25%	50%	25%
Less	Less	Very	0%	0%	100%
Very	Less	Less	80%	20%	0%

Table 3. Example of some of the possible matrix combinations.

Comparison of Safety Metrics

Throughout the network development both the EEM method and Personal Risk from Urban KiwiRAP were compared. It was determined that the Personal Risk from Urban KiwiRAP was more suitable than the EEM due to the Personal Risk giving a risk rating relative to each individual on the road.

The EEM methods proved more suitable to determining how different road design features would affect the number of crashes along midblocks or at intersections. The EEM methods primarily increase the risk based on the number of vehicles using the road (AADT). Figure 4 displays this characteristic by classifying the motorway as high risk. As the number of vehicles using the road decreases, the risk of a crash happening decreases. Conversely, the Personal Risk from Urban KiwiRAP looks at historic crashes, determines an overall risk rating and then assigns a risk rating relatively to each individual travelling along the road. The motorway has a high number of users and the number of crashes along this section is low enough to give the section of road a low risk to each individual vehicle. As you move off the main roads the number of vehicles decreases and the relative number of crashes increases. Therefore we see a higher risk rating given by the Personal Risk.

Figure 4. Comparison of EEM methods (left) and Personal Risk from Urban KiwiRAP (right). Note the differences between the motorway (centre right, top to bottom).

Website Development

A website was developed that allows for a user to calculate routes using the developed matrix (Figure 3). The website was built using ESRIs JavaScript API (Application Program Interface). It allows for a user to calculate a route in the Greater Auckland region and then compares their route with the shortest and fastest route between the two locations (Figure 5). This allows for the user to quickly identify where the route varies and helps them to make a better decision when choosing their route. A popup displays some simple statistics providing a quantifiable comparison between the routes (Figure 6).

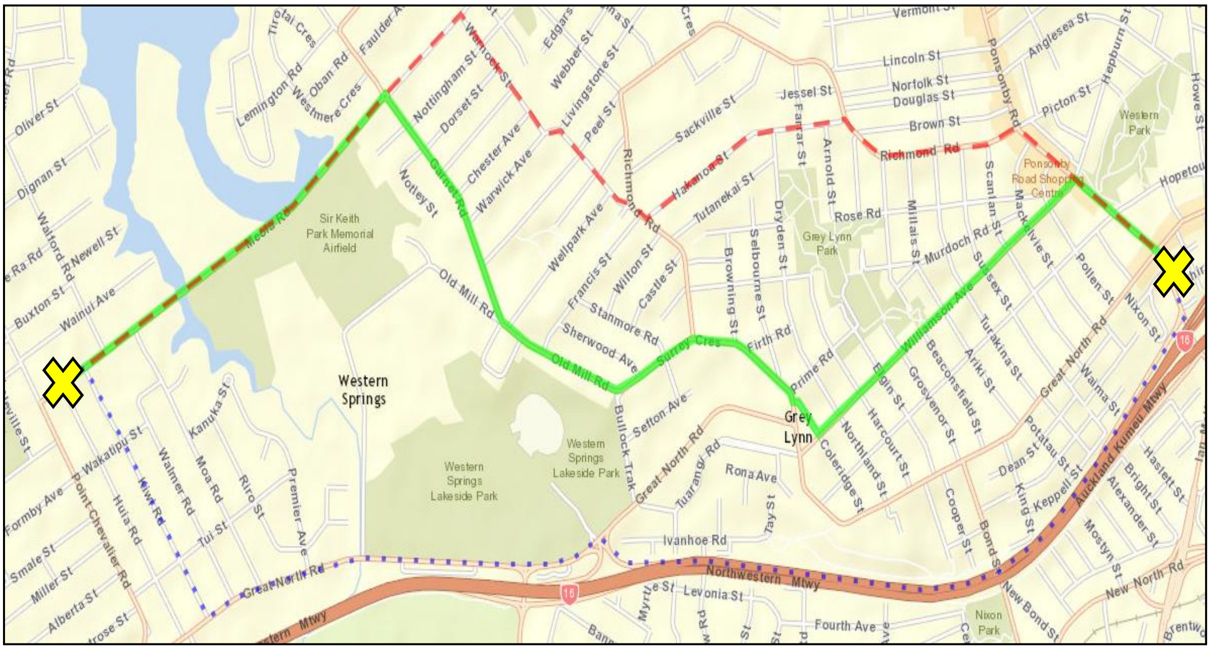

Figure 5. The route chosen using the matrix (solid green) is compared with the shortest (dashed red) and fastest (dotted blue) routes.

RESULTS

The result of this project shows that vehicle routing using safety metrics is feasible. However the project did indicate that advancements or other methods to quantify safety are required for complete coverage. The resulting network using the Personal Safety metrics from Urban KiwiRAP did not provide coverage for all roads. Roads with fewer than four crashes in the past five years were unable to have safety metrics calculated for them.

Due to the constraints of the GIS software used, a method of weighting had to be developed. This provided a sufficient alternative to the Resource Constrained Shortest Path Problem. This method of weighting can be easily adapted to run on data for different regions.

The deliverable (the interactive website) was built using ESRIs JavaScript API. This provided a robust platform to develop the website.

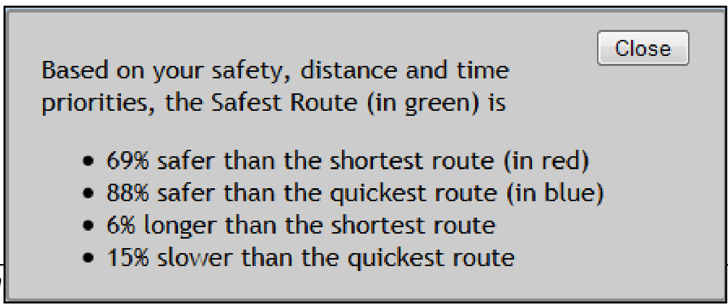

Figure 6. Popup showing the quantifiable statistics.

DISCUSSION

This project demonstrated that it is feasible to incorporate and use safety metrics for vehicle routing.

Resource Constrained Shortest Path Problem

During this project the Resource Constrained Shortest Path Problem (RCSPP) was encountered. The RCSSP involves finding the least cost path between two locations when a secondary constraint (impedance) is placed on the network. ArcGIS is not able to solve the RCSPP. Therefore an alternative workaround needed to be implemented. This involved the use of weightings and an associated matrix allowing a user to specify how important they found safety, distance and time. This method of weighting was not ideal, but produced satisfactory results.

If this project was to be further developed then it would be beneficial for the RCSPP to be solved. It allows for greater flexibility when routing using a secondary impedance. ArcObjects (ESRI) is a scripting language that would facilitate the development of a custom routing tool. Such a tool could be designed to solve the RCSPP. Further study would need to be performed to determine the most efficient method(s) of solving the problem.

Safety Metrics

From the two safety metrics examined, the Personal Risk from Urban KiwiRAP was determined to be the more suitable of the two. This was due to the fact that it gives a risk rating relative to the individual travelling along the route. Urban KiwiRAP is part of the International Road Assessment Program (iRAP) which defines three RAP protocols: risk mapping, Star Rating and performance tracking (Brodie, et al., 2015). Urban KiwiRAP safety metrics are derived from the risk mapping protocol and as a result are removed from the specific design features of intersections and corridors.

Due to how the Personal Risk metric from Urban KiwiRAP is calculated, only 52% of all roads in the study area had a risk calculated for them. For the Personal Risk metric to be calculated, each road had to have had four or more crashes occur in the past five years. Generally, this was limited to higher volume, main roads. As a result, the majority of low volume, often residential streets, did not have a risk value calculated.

Currently, Star Ratings are only available (in New Zealand) for the State Highways. Star Ratings are derived from the engineered safety features on roads. Roads with more safety features (such as wider lanes and sealed shoulders) are given a higher star rating. As Star Ratings begin to be calculated for urban regions within New Zealand it should be possible to use these proactive metrics (opposed to the reactive metrics from Urban KiwiRAP and predictive metrics from the EEM) as a full coverage method of quantifying safety.

Vehicle Routing Network

The most substantial limitation of this project was the lack of a fine tuned, dependable VRN. The network was built using only the most basic of information and as a result, is only suitable for the purpose of a feasibility test. A reliable and accurate VRN requires at least predictive traffic estimates (based on time of day) if not real-time traffic, road disruptions and crash data.

Often this data is only available through commercial partners. More basic information, such as more reliable topology (connectivity), turn restrictions, one-way data and lane information can be sourced from open source, free to use sources. One of these is Open Street Map (OSM). OSM uses Volunteered Geographic Information (VGI) to build, develop and maintain information about our roads. This data is free to use and numerous tools exist to acquire the data and transform it into a usable VRN.

The methodology used in this feasibility test can easily be scaled, adapted and developed to suit new regions and new data through the flexibility and power of GIS.

Website

When it comes to road safety people often have the understanding that if they drive safe, then they will be. It doesn't occur to them that road (safety) features (or lack thereof), travel speed and vehicle safety features can effect either the likelihood or outcome of a crash. Therefore by developing a simple, easy to use website the message of road safety can be reiterated to road users.

The Safer Journeys Strategy aims to reduce the number of crashes on roads within New Zealand. The website provides both a graphical, and quantifiable result for drivers when they calculate a route. This helps drivers understand why the routes displayed vary and allows them to make more educated decisions when travelling by vehicle.

CONCLUSION

This project has proven that routing using safety metrics is feasible. By exploring two different existing methods of quantifying road safety, a suitable metric was found. The Personal Risk from Urban KiwiRAP is suitable for such an application as it provides a risk rating relative to an individual on the road. However, due to the way its calculated only 52% of roads within the test area had a metric calculated. The remaining had a minimum risk rating applied.

To incorporate the road safety metrics into a VRN, a method of weighting was developed. Due to project constraints, the RCSPP was not able to be solved and as a result it has been identified as an area for future development. The VRN network used only the necessary data to construct a VRN. For a reliable and accurate network, a partnership with a commercial data supplier would need to be established.

The final deliverable of this project was a website. This allows for a road user to understand how safety can affect their routing and travel decisions. It encourages them to travel along safer routes and make them aware of road safety.

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