Simplification of road improvement option selection processes using the generic countermeasure model

Leijie Xu

School of Traffic and Transportation, Beijing Jiaotong University, Beijing, 100044, China

Corresponding author's e-mail: 16120910@bjtu.edu.cn

Abstract. This paper simplifies the road improvement option selection process within Safer Road Investment Plans to make it more suitable for strategy analysis or road networks. This simplification is needed to reflect the management function in the road management cycle that differs from the iRAP (International Road Assessment Programme) methodology. It studies Road Safety Policy Tools embodied in the iRAP, designed to increase road safety, through a review of the literature, with a focus on Safer Road Investment Plans. Based on the analysis of road improvement option selection processes and data integration, the paper develops a generic countermeasure model to assess road conditions and to screen road-works. In addition, the model was applied to two case studies of strategic roadwork plans. The project-level results were obtained through deep analysis of road attribute data. The results showed that the generic countermeasure model could lead to similar treatment plans using similar budget, which demonstrated its feasibility and opens up possibilities for its further extension.

1. Introduction

In a report of the Secretary-General, *Progress towards the Sustainable Development Goals* (2017), road safety was incorporated into the Sustainable Development Goals for the first time by the UN (United Nations). Halving road deaths and injuries has now become a United Nations Sustainable Development Goal, alongside other major social justice and health issues, such as clean water and maternal health rights. iRAP (International Road Assessment Programme) is a master plan for Road Assessment Programmes (RAPs) that was created to help address the socially devastating and economic costs of road traffic accidents. It was founded as a charity in England in 2006 and is the leading organization for regional Road Assessment Projects, alongside other programmes, such as EuroRAP, UsRAP and AusRAP (the Australian Road Assessment Programme). iRAP believes that improving roads to a higher standard is a key way to achieve the Sustainable Development Goal target. It encompasses four road safety policy tools that were developed by combing the work of these existing regional Road Assessment Programmes and the expertise of the world's leading road safety research organizations. Its purpose is to save lives by reducing road trauma, which uses a variety of road safety policy tools, including Risk Mapping, Star Rating, Safer Roads Investment Plans and Policy as well as Performance Tracking.

Star Rating is used to allow for simple and objective judgments and measurements on the level of road safety provided by road designs. In star rating systems, five-star roads are the safest while one-star roads are the least safe. Broadly speaking, the number of deaths and serious injuries will be halved for each star rating score increase. For all new roads, a minimum of a three-star target is deemed to be the starting point [1]. The Safer Road Investment Plans seek to achieve a more economical and

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

affordable combination of road improvement options, ones based on individual road conditions. iRAP considers more than 90 proven road improvement options that can be used to generate safer road investment plans and improve road's star ratings. In turn, this will lead to an improvement in road safety since road safety treatments will contribute directly to a reduction in injuries and fatalities [2]. Besides, risk maps illustrate that the actual number of deaths and injuries in the road network through detailed collision data. Performance Tracking is a combination of Star Rating and Risk Mapping to track road safety.

This report concentrates on the methodology and processes involved when iRAP is used to inform safer road investment plans at the project level. It offers a simplified discussion of different management functions involved in the road management cycles; in so doing, it sees that strategic planning is more general, whereas the project level involves more focus on implementation, operation and evaluation. First of all, through a literature review, the report discusses the iRAP methodology of producing road investment plans and discusses its theoretical basis. Then, according to iRAP-based theory and the conclusions offered on the economic impacts of road treatments within the Road Safety Toolkit, a generic countermeasure model for selecting road treatments was developed, drawing on the data that was collected. In addition, two project cases from iRAP were chosen to assess the viability of the model, these were the Section B project (Sankeys Road to Traveston Road) in Australia and the A404 road upgrading project, in Amersham, England. It obtains treatment plans at strategic level first and then inform further selection to produce treatment plans at the project level, with an emphasis on road attributes. It confirmed the possibility of the generic countermeasure model for the strategic analysis and the applicability of the further selection method at operational levels since it obtained similar treatment plans to iRAP.

2. Road improvement option selection process

The iRAP methodology fact sheet 11 (2015) introduced specific processes of roadworks selection at project level. Triggers are tested for every road improvement options first, and roadworks not activated are eliminated. Generally, triggers are a function of one or more of star ratings, road attributes as well as vehicle volume. For each activated option, the number of deaths and serious injuries that may result from its separate installation is calculated. Economic tests are also conducted. That is to say, a Benefit Cost Ratio (BCR) must exceed the prescribed threshold. Then, options that fail the standard are further eliminated. The BCR in the economic tests is the ratio of the present value economic benefit to the present value economic cost. iRAP clarifies that present value economic benefits are related to the number of deaths and serious injuries prevented, the economic value of human life and the economic value of serious injuries [3]. In the iRAP model, the number of death and serious injury is calculated by the proportion of star scores before and after installing roadworks. It assumes that the external factors such as the vehicle speed, vehicle flow and the ratio of fatalities to serious injuries are constant. In addition, McMahon and Dahdah (2008) concluded an empirical rule that correlated the economic value of human life and the economic value of serious injuries to the national GDP per capita. For another, the economic cost is calculated based on the construction cost and service life data of each option.

After completing economic tests of available options installed independently, it is necessary to check whether they follow the rules of minimum length, minimum spacing and hierarchy. The individual options are then adjusted by determining the impacts of all available options at every 100-metre road sections and the total causalities after applying multiple feasible roadworks for each collision type. Finally, when the road improvement option selection process is completed to obtain complete plans, iRAP conducts final economic analysis and develops safer road investment plans.

3. The generic countermeasure model

3.1. Road improvement options classification

As mentioned above, there are a total of 94 road improvement options can be applied at 100-metre segments of roads in the iRAP model. However, considering such a detailed classification of roadworks is unnecessary for strategic planning. Therefore, the first step is to group options by the nature of roadworks into treatments. In the generic countermeasure model, these 94 roadworks are classified into 42 treatments, which have the corresponding levels of cost, effectiveness as well as treatment life in Road Safety Toolkit. For example, the cost of treatments in Road Safety Toolkit is categorized into five groups: high, medium-to-high, medium, low-to-medium and low cost. What's more, the generic countermeasure model should also take into account budgets other than cost, effectiveness and treatment life. Therefore, there is a need to determine the types of budget for treatments, such as capital budgets primarily from the public and recurrent budget used for operation and maintenance (periodic works and routine works).

3.2. Criteria

The criteria evaluating the condition of road network contained three parts: criteria categories, indicators' weight and scores at different grade of indicators. Regarding choosing criteria categories, this model selected road hierarchy, traffic volume and Star Rating Scores (SRS) to assess road condition similar to the iRAP model using triggers such as SRS, road attributes and vehicle flow. Furthermore, traffic volume was further subdivided into three indicators: vehicle, pedestrian and bicycle as well as motorcycle.

About all indicators' scores, their ranges are consistent from 1 to 5. The model graded each indicator into 4 or 5 level taking into account road safety factors. The smaller the possibility each level leads to road crashes is, the lower the scores are. For the criteria of SRS, iRAP has already evaluated roads as 1 to 5 stars. Thereby the higher the SRS are, the lower criteria's scores are. Also, indicators' scores rise with the increase of traffic volume. As far as the relationship between road hierarchy and road safety, statistics released by the Department for Transport indicated that rural roads were actually more likely to crashes than motorways in UK. Despite the low traffic on rural roads, the number of casualties on rural roads in 2013 was almost seven times that of motorways and the number of fatalities is almost ten times higher. Meanwhile, there were similar conclusion by Albalate and Bel (2012) that motorways appeared to contribute to road safety when analysed the evidence from Europe without distinction between charges. Hence, the model determined that the score of motorways is 1 while that of rural roads is 5. For another, the weight determined is according to the proportion of road accidents. The complete criteria categories, their weights defined can be seen in Table 1. Thereby the conditional index suggesting road conditions related to road safety can be calculated.

Table 1. Criteria categories and weights

Criteria Categories			Weight
SRS (Star Rating Scores)			0.6
Traffic Volume	Vehicle(vehicles/day)	0.7	0.25
	Pedestrian/Bicycle	0.2	
	Motorcycle(vehicles/day)	0.1	
Road Hierarchy			0.15

3.3. The generic countermeasure model definition

The definition of the generic countermeasure model demonstrated that which level of treatments is required for roads and their constraints for treatments selection. As can be seen from Table 2 that the range of condition indices is also from 1 to 5. The higher the score means the worse the road safety so that a higher degree of treatments is required. For a perfect road with score 1, a small amount of low-cost operational treatments is still needed, which could be named as do minimum. However, there are no excessive requirements for the effectiveness and treatment life. On the contrary, for dangerous

roads with scores up to 5, almost all kinds of budgets of treatments should be arranged, which is do maximum. What's more, their costs would also be relatively high and would have higher requirements for effectiveness and longevity. As for roads with moderate conditions, as the index score increases, the degree of the selected treatments and the requirements for budget, cost, effectiveness, and life expectancy are progressively enhanced, which are low, medium and high level respectively.

Table 2. The generic countermeasures

Condition Index	Level	Constraints			
		Budget	Cost	Effectiveness	Treatment life
1	Do minimum	Operation	Low	>10%	>1 years
2	Low	Operation	Low Low to medium	>10%	>1 years
3	Medium	Operation, Routine, Periodic	Medium	>25%	>5 years
4	High	Operation, Periodic, Capital	Medium to high High	>25%	>10 years
5	Do maximum	Operation, Routine, Periodic, Capital	High	>25%	>20 years

4. Case studies

This section selected two cases in Australia and England respectively to prove whether this model is suitable for the roads in the real world. They have already concluded appropriate road treatments using iRAP methodology and utilized them on the real world.

4.1. Condition index

The first case is Section B project (Sankeys Road to Traveston Road), which is a part of the Bruce Highway (Cooroy to Curra) Upgrade in Australia. This section used to be one of the deadliest highway in the country. According to statistical data from AusRAP, the length of Sankeys Road to Traveston Road is 12 km. It was an arterial road with 15,700 vehicle/day in 2009 and was star rated as 2 stars for the whole road. Besides, the number of pedestrian, bicycle and motorcycle volume is at medium level. After adopting the $513 million project of the road treatment plan by iRAP, AusRAP conducted a before and after star rating assessment of Section B, identifying safety improvement from 2-stars to 4 and 5-stars after upgrading infrastructure. In addition, its assessment suggested that the risk of death and injury was reduced by more than half as the star rating increased. Compared with the old Bruce Highway prior to 2010, fatal and serious injuries were reduced by 82% in the three years after opening.

The second case is A404 road upgrading, located in Amersham, England. As reported in the British EuroRAP Risk Mapping Results [4], it was a typical example of low-cost maintenance improvements and local safety schemes. The infrastructure upgrades completed in 2010 were both low cost and straightforward. Star Rating Scores of the A404 has increased from 56% 2-star, 23% 3-star and 21% 4-star to 39% 2-star, 28% 3-star and 33% 4-star. Simultaneously, it was improved from "medium-high risk" to "low-risk" route with a reduction in fatal and serious accidents from 12 to 1. In this model, the average score of star rating scores with 3.35 stars prior to 2010 was used to calculated its condition index. In addition, statistics released by the Department for Transport (2009) suggested that there were 13,155 vehicles per day and 188 heavy vehicles per day. The number of motorcycles was 59 vehicles per day, which its score is 3 and the other flow is in the low range. The indicator scores determined based on actual data and condition indices of two cases calculated are 3.55 with Bruce Highway and 2.96 with A404 respectively.

4.2. Treatment plans

It can be seen the condition index for Section B of Bruce Highway is 3.55, which is in the middle range between 3 and 4. Both medium level and high level need to be taken into account in the treatments selection process. Since the types of operation and periodic treatments were duplicated in both levels for budgetary constraints, it just chose routine treatments in the medium level while selected all budgetary types in high level. Similar to Section B of Bruce Highway, middle-level treatments are adopted for A404 highway since the condition index is extremely close to 3. Under the constraints of budgetary, cost, effectiveness and treatment life, the treatment plans at a strategic level can be obtained.

Further considering the road attribute data and the unit cost of the measures, treatment and investment plans at the project level can be produced. First of all, the length of Section B analyzed was relatively long with 12 km, the treatment of additional lane with high cost was uneconomical. Secondly, it was not an urban road and the number of pedestrian was extremely low, the treatments used for urban roads with high pedestrian volume such as service road, pedestrian crossing, restrict/combine direct access point as well as traffic calming are redundant. When focused on treatments themselves, there were two similar types for realignment and intersection. The horizontal realignment and grade separation intersection were selected due to economy and traffic volume. Similarly, since there is no intersection and railway on the A404, the treatments of intersection and railway crossing can be removed in the treatment plan. In addition, the safer road investment plans were also produced based on final treatment plan and the unit treatment cost. Table 3 and Table 4 presented the investment plans including treatment plans of Bruce Highway and A404 at project level respectively. It can be seen that in the Bruce Highway investment plan with a total asset budget of $ 518.748 million, $516 million come from the capital budget, $2.748 million from the recurrent budget while in A404 road investment plan, all asset budgets were from recurrent budget with £802.6 thousands.

Table 3. The treatment and road investment plan for Bruce Highway

Budget	Treatments	Cost ($ million)	Sum ($ million)
Capital	Realignment-Horizontal	144	516
	Duplication	192	
	Intersection-Grade Separation	180	
Routine Operation	Median barrier	1.98	2.748
	Roadside Safety – Barriers	0.768	
Sum			518.748

Table 4. The treatment and road investment plan for A404 road

Budget	Treatments	Cost (£ thousands)
Operation	Pedestrian Crossing - signalise	52.5
	Speed Management	13
	Shoulder Sealing	70
	Roadside Safety – Barriers	85
Periodic	Road Surface Rehabilitation	34
Sum		802.6

5. Comparison and Discussion

5.1. Treatment plans comparison

Judging from the iRAP schemes of the two case, the plans generated by the generic countermeasure model did not differ significantly in the selection of road treatments and the overall budget from iRAP. On the whole, they resulted in more treatments than iRAP. For example, the scheme obtained for Bruce Highway had only one more treatment than iRAP, which was horizontal realignment with capital budget while for A404 road it adopted roadside safety barriers and shoulder sealing with medium cost rather than delineation and un-signalise pedestrian crossing with low cost. As a result, the total budget cost derived from the developed model would be slightly larger than that of iRAP with $ 518.748 million for the generic countermeasure model and $ 513 million for iRAP method.

The reason for these subtle differences in these two cases was that the information obtained were incomplete. The data of road attributes could only be collected through the internet such as the projects background from AusRAP and EuroRAP or Google map. The treatments were screen out only by some aspects such as pedestrian and bicycle flow, motor vehicle volume or whether there were intersections or not. Besides, it could not be detailed at the 100-meter road level. If more detailed information could be gathered through field investigations, the treatment plans will be closer to iRAP. However, in general, this model was feasible for strategic analysis or road networks planning. On the other hand, it can be seen from the safer road investment plans of the two cases, road conditions have a great impact on the treatment selection and total costs of subsequent roadworks to guarantee the road safety. For various levels of road conditions, the difference in the cost of roadworks is enormous. For example, the gap between the cost of medium-level road conditions and that of medium-to-high road conditions is the order of magnitude of thousands and millions. Therefore, it is greatly meaningful that iRAP regulates minimum 3-star targets are the starting point for all new roads and rehabilitated roads.

5.2. Selection process comparison

From the comparison of the selection process of two methodologies, they are both based on the road attributes and road condition data to screen road treatments so as to obtain treatment plan and road investment plan. The distinction is that they undertake the different management functions in the road management cycle. The generic countermeasure model is relatively general and simplified, which is a decision-making method at the strategic level for road networks. On the contrary, the methodology of iRAP is more specific and precise, which is a decision-making method at the 100-meter project level. Therefore, the advantage of the generic countermeasure model is that it is a simplification of the iRAP method at the strategic level. The selection process and calculation are simple and fast.

In the treatment selection process of iRAP, triggers such as Star Rating Scores, traffic volume and road attributes are required to trigger all roadworks one by one, and economic analysis on the number of collision casualties at 100-meter road sections should be carried out to adjust the plan. Thereby adopting this process is quite a huge workload and too detailed if assessing the entire road network at strategic levels. Instead, the general countermeasure model regards some triggers (Star Rating Scores, traffic flow and road hierarchy) as the criteria to evaluate road conditions. Then, it selects road improvement options on the basis of the assessment of road conditions. About economic test, it utilizes economic conclusions associated with road treatments in iRAP Toolkit, which are treatment cost, effectiveness and life as constraints. It not only simplifies the process but also takes into account the economic analysis, road attributes and other factors. In addition, the budget types are also considered, which is more suitable for the strategic analysis of road networks.

6. Conclusion

This paper studies a core issue, how to select the road improvement options that are to be included in Safer Road Investment Plans. Due to the different management functions in the road management cycle, this process was simplified and improved on the basis of the existing methods and theory underpinning the iRAP model. A generic countermeasure model for selecting road-works was developed, one which is applicable to road network analysis.

First of all, road improvement options were classified into 42 kinds of treatments, according to the specifics of particular road-works. Road conditions were then evaluated using Star Rating Scores, road

hierarchy and traffic volume as selection criteria, which were similar to triggers in the iRAP. The second step defines the grade of particular indicators, their scores and particular weightings for each level according to the type and size of the traffic volume, the level of the road hierarchy and the SRS. Then a generic countermeasure model was defined, which constrained budget, cost, effectiveness and treatment life on the basis of different road condition indices. They have already been calculated on the basis of statistics within iRAP Toolkit. In other words, assessing road condition indexes simplifies the triggering of road improvement options and the definition of the generic countermeasure model simplifies the economic test process in iRAP methodology. Finally, it conducted two case studies in order to confirm the feasibility of the established model and to evaluate the model. The model developed was applied to derive results at the planning level, after which road attribute data collected on the internet was used to obtain project-level results. It obtained similar road treatment and investment plans to those within iRAP, confirming its suitability of both the generic countermeasure model for strategic analysis and the possibility of the application of expanding methods at project level.

References

[1] International Road Assessment Programme, (2009). Star Rating Roads for Safety: The iRAP Methodology. Basingstoke. Hampshire. UK.
[2] International Road Assessment Programme. (2014). iRAP Methodology Fact Sheet 1: Overview. http://resources.irap.org/Methodology/iRAP%20model%20factsheet%201%20-%20Overview.pdf.
[3] International Road Assessment Programme. (2015). iRAP Methodology Fact Sheet 13: Economic analysis. http://resources.irap.org/Methodology/iRAP%20model%20factsheet%2013%20-%20Economic%20analysis.pdf.
[4] Road Safety Foundation. (2014) How Safe Are You On Britain's Roads? Basingstoke. Hampshire. UK.
[5] Albalate, D., Bel, G. (2012). Motorways, tolls and road safety: evidence from Europe. SERIEs, 3(4), 457-473.
[6] AVIVA. (2016). Safest route: Motorways vs country roads. https://www.aviva.co.uk/news-and-guides/article/safest-route-motorways-vs-country-roads/.
[7] Department for Transport. (2009). Traffic Counts. https://www.dft.gov.uk/traffic-counts/download.php.
[8] Department for Transport. (2013). Road accidents and safety statistics. https://www.gov.uk/government/collections/road-accidents-and-safety-statistics.
[9] UN Economic and Social Council. (2017). Progress Towards the Sustainable Development Goals. pp. 4-6.
[10] International Road Assessment Programme. (2015). iRAP Methodology Fact Sheet 11: Countermeasures.http://resources.irap.org/Methodology/iRAP%20model%20factsheet%2011%20-%20Countermeasures.pdf.
[11] McMahon, K., Dahdah, S. (2008). The True Cost of Road Crashes, Valuing life and the cost of serious injury. London: iRAP.