The Unified Reliability Model

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Abstract

Reliability of products and systems are fundamental to consumer choice. In the context of transport systems, journey time reliability is seen as a key determinant of traveller choices. Existing research has found that on-time arrival can be valued more than travel time savings. Thus, the quantification of reliability is paramount to monitoring and assessing the performance of transport systems, especially considering road transport systems.

This paper presents the development of the Unified Reliability Model (URM), a supplementary tool for the simple and robust measurement of reliability on a road network. The URM unifies aspects of the UK Reliability Model and the New Zealand (NZ) model, both of which are currently applied as best practice. Applications of the URM using data from the Sydney road network present robust measurements of reliability that are comparable or exceed the accuracy of the existing approaches.

1 Introduction

Existing reliability models tend to focus on travel time, trip length and traffic flow as the key independent variables that affect reliability (Taylor, 2013, Tu et al., 2012). These models do provide a sound foundation for reliability analysis but fail to capture temporal impacts, proximity to urban centres and road capacity limitations of the network. Accordingly, separate model estimations are necessary to understand each unique scenario posing a practical concern of utilising outputs from a variety of models. Though multiple models can be advantageous for microscopic context based analysis of reliability, providing a holistic overall assessment of reliability can be incredibly useful for project ranking in a strategic planning environment (Day et al., 2015). The Unified Reliability Model (URM) aims to unify these segregated models as well as capturing additional relevant independent variables. The URM model can effectively

simplify the application of reliability assessments for practitioners and decision makers.

2   Model structure

The URM is an adaptation of the 'UK Model' published by the UK Department of Transport (Black et al, 2009), which estimates the standard deviation of travel time (σ_{ij}) as a measure of the reliability using the distance along the road section (d_{ij}) and the expected journey time (t_{ij}) and related as follows: $\sigma_{ij} = A \times t_{ij}^b \, d_{ij}^c$. The coefficients "$b$" and "$c$" (expected journey time and distance along the road section) are estimated to define the model. The URM adopts the Cobb-Douglas functional structure of the UK Model but also incorporates additional variables using an exponential function that accounts for the time of day, proximity to major traffic generating land uses and the capacity of the road section. The URM is defined as follows:

$$\sigma_{ij} = e^{A + \alpha X_1 + \beta X_2 + \gamma X_3} \, t_{ij}^b \, d_{ij}^c$$

Where,

X_1: represents the distance of the road section from the CBD

α: coefficient of X_1

X_2 is the assumed HCM capacity of the infrastructure (Motorway = 2200pc/hr/lane, Arterial = 1800pc/hr/lane, Austroads)

β: coefficient of X_2

X_3 is the definition of peak and off-peak period (binary variable, 0 for off-peak, 1 for peak)

γ: coefficient of X_3

A is the calibration constant.

The "distance from CBD" variable (X_1) depicts proximity to urban centres. Congestion and travel demand tends to increase closer to the CBD, particularly in Sydney, and thus is important to capture when modelling reliability. This variable is measured by considering the furthest straight-line distance of a point on the route to the CBD, thus each route will have a static value for the "distance from CBD" variable. The capacity (X_2) variable is the assumed HCM capacity of the infrastructure, in the context of this study, the capacity was defined based on the road hierarchy. Motorways and Arterial routes were considered and accordingly the theoretical capacities of this infrastructure were used for the model. However, it must be noted that this is a continuous variable and capacity estimates derived from the fundamental diagram (using flow and density data) can also be used to better constrain the model.   The temporal impacts on reliability are accounted for using a binary variable which indicates peak and off peak conditions (X_3). The UK model structure was utilised to take advantage of the ability to linearize the model and estimate it using simple regression techniques whilst capturing a variety of independent variables and maintaining the integrity of the reliability assessment. The linearization of the model is presented below.

$$\ln(\sigma_{ij}) = A + \alpha X_1 + \beta X_2 + \gamma X_3 + b\ln(t_{ij}) + c\ln(d_{ij})$$

3 Model estimation

The URM was estimated using 18 months of travel time data collected across 37 bi-directional routes in Sydney. As a means of comparison, the UK model was also estimated with the same data sources. Estimation of the URM model was an iterative process where insignificant or collinear variables were omitted. For example, the distance from CBD variable and the inner/middle/outer ring classification variable were considered to be correlated and as such removed from the model.

Table 1 presents a comparison of the UK model and the URM. The URM has intuitive coefficient estimations consistent with existing reliability models.

- Greater route travel times result in greater unreliability (positive 'b' coefficient).
- Shorter distances have greater unreliability (negative 'c' coefficient).
- Peak periods are less reliable than off-peak periods (positive 'γ' coefficient)

Furthermore, the URM model had a superior goodness of fit (R-square value of 0.59) as compared to the UK Model (R-square value of 0.37) which highlights its potential as a supplementary approach to describing the reliability of key transport routes.

Table 1: Comparison of Model Estimation (UK Model and URM)

Coefficients and Statistics	UK Model	URM
Intercept – "A"	0.0075	-19.0339
ln(tij) (b- parameter)	1.5592	2.8496
ln(dij) (c- parameter)	-0.4850	-1.8875
Distance from CBD: (α-parameter)		
Capacity: (β - parameter)		0.0044
Peak: (γ - parameter)		0.3923
Inner/Middle/Outer Ternary: (δ – parameter)		0.2517
R Square	0.3692	0.5910
Adjusted R Square	0.3689	0.5905
Standard Error	0.8700	0.7008
Sample Size	3575	

4 Potential of the Unified Reliability Model

Estimation of the URM revealed improved goodness of fit results as compared with the UK model which highlights its potential as a supplementary approach to describing reliability of key transport routes. However, further research must be conducted to verify and validate this approach. Furthermore, the URM has some limitations in application. The URM requires additional data, outside of travel time data and route distance. The route capacity and a categorical definition of the functionality of the route are necessary to calibrate and apply the model which may be difficult to collect. The other key limitation is that though the URM captures more variables and factors which have been shown to affect reliability of a road network, there is scope to consider other factors (such as weather, land use, fleet mix, driver demographics, etc.) and further build or modify the structure of the URM. Overall, based on the model estimation results, it is evident that the URM does provide the foundation to develop a singular holistic model to further understand reliability of road network.

5 References

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