PROPOSED NEW PERFORMANCE INDICATOR - VEHICLE OPERATING COST INDEX (VOCI) DUE TO ROAD ROUGHNESS

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The New Zealand Ministry of Transport has stated that reducing transportation costs should be a key outcome of the use of the National Land Transport Fund. Road roughness contributes to the cost of transportation through factors such as fuel consumption, repairs and maintenance, and tyre wear. The cost due to roughness may be only a few cents per vehicle kilometre travelled (VKT), but with circa 20 billion VKT on the State Highway network each year the total cost can be significant. Currently the performance of the State Highway network is measured using the International Roughness Index (IRI) and Smooth Travel Exposure (STE); however, neither quantifies the cost due to roughness and neither are suitable surrogates.

This paper presents a proposed new performance indicator, the Vehicle Operating Cost Index (VOCi) which returns the average vehicle operating cost due to road roughness per VKT. The VOCi has been applied to the entire New Zealand State Highway network, with results presented for each State Highway functional classification, at both the national and regional levels. Although nationally the magnitude and variability of VOCi reduces with increasing functional classification, as is consistent with appropriate stewardship of the asset taking account of the relative functional importance of the route, the same relationship does not always exist at the regional level. It should be noted, however, that the VOCi, like any other indicator of its kind, is only part of the information available to decision makers and will not negate the need to ‘drill-down’ to determine if there are any underlying reasons behind uncharacteristic values.

Keywords: Vehicle operating costs, roughness, performance management, maintenance and renewals.
INTRODUCTION
The New Zealand Ministry of Transport’s Government Policy Statement (GPS) on Land Transport Funding (1) identified seven short- to medium-term impacts that should be achieved through the use of the National Land Transport Fund (NLTF). These include impacts that contribute to economic growth and productivity such as “improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation”, as well as other impacts related to road safety, the environment, transport choice and health. The GPS also calls for a “sharper and broader focus on value for money”, requiring “demonstrable value for money across all aspects of the development, delivery and management of the National Land Transport Programme” (1).

The New Zealand Transport Agency (NZTA), the government agency responsible for the management of the New Zealand State Highway network, responded to the GPS by developing a performance framework which links the Ministry’s stated impacts in the GPS through to the relevant activities and outputs of the various NZTA business units. Of particular interest to this study, is the link between the Ministry’s desire to “lower the cost of transportation” and the contribution to this impact made by maintenance of the State Highway network. The key impact of maintenance work on the cost of travel is the effect on the magnitude of vehicle operating costs (VOC) caused by road roughness; other travel costs such as travel time costs tend to be affected by capital works projects, as they provide additional road capacity and reduced trip distance.

A rough or irregular road surface contributes to the cost of transportation by causing an increase in VOC through fuel consumption, vehicle repairs and maintenance, tyre wear, lubricating oil consumption, and vehicle depreciation (2). The New Zealand State Highway network consists of approximately 11,000 kilometres total carriageway length and caters for circa 20 billion vehicle kilometres travelled (VKT) each year. Clearly, aggregated across 20 billion VKT, the VOCs can be significant and even a small percentage decrease in VOC is a significant saving to the economy.

However, the NZTA does not currently report on VOC due to roughness; rather, it reports on Smooth Travel Exposure (STE). STE is an exception-based measure which reports “the proportion of travel that is undertaken on roads with conditions above the targeted conditions for those roads” (3). In New Zealand, the target condition is set at a roughness level of 150 NAASRA (National Association of Australian State Road Authorities) Counts (4). This is equivalent to an International Roughness Index (IRI) of 5.71. Because STE only reports the percentage of travel occurring on roads that are in an acceptable condition in terms of roughness, it does not take into account the shape of the roughness distribution, concentrating instead on only those sections with a roughness level smoother than a set value. Assuming all other variables are equal, the hypothetical example in Figure 1 highlights this issue. Although the two distributions shown result in a similar STE value, the distributions are significantly different. This is particularly significant given the fact that VOC increases with increasing roughness. In addition, the Ministry’s objective is to lower transportation costs, not necessarily to provide a certain minimum level of comfort to a percentage of users. STE, therefore, appears to be an inappropriate tool for monitoring network performance in terms of transportation cost.

This paper, therefore, proposes a new Key Performance Indicator (KPI), designed to calculate the additional VOC per VKT due to road roughness. The KPI is then applied to the entire New Zealand State Highway Network using existing network data, and the performance of the national and regional networks compared and contrasted.
NEW ZEALAND VEHICLE OPERATING COST (NZVOC) MODEL

To maintain consistency with the way NZTA economic assessments are currently undertaken, this study has adopted the methodology for calculating VOC due to roughness as set out in their Economic Evaluation Manual (EEM) (5). This calculation is based on the New Zealand VOC (NZVOC) model.

Research by Bennett (6) led to the development of the NZVOC model and its subsequent updates (7,8). The NZVOC model drew on the available Road Transport Investment Models (RTIM) and Highway Development and Management (HDM) models at the time (9,10,11), and assessed their applicability to New Zealand roads. This progression has led to the current version of the NZVOC model which uses VOC relationships primarily based on those from the World Bank’s Highway Development and Management (HDM-4) model (12), appropriately calibrated to New Zealand conditions using local data (13).

The major difference between the current NZVOC model and the earlier VOC models is the way in which the various factors affecting VOC have been treated. The approach taken for determining VOC is to calculate a base running cost and then include additional costs as appropriate. The base running cost consists of fuel consumption, tyre wear, lubricating oil consumption, vehicle parts and maintenance, and use-related vehicle depreciation, and is dependent on speed, gradient, vehicle class and road type. The additional costs include the effects of roughness, commonly recognised as a key factor affecting VOC (14,15,16), and are dependent on road category (urban or rural), vehicle class and road roughness measured in IRI.

VOC INDEX CALCULATION

Data Source

The data source for this study is NZTA’s Long Term Performance Measurement Data Warehouse, which contains data extracted from the Road Asset and Maintenance Management (RAMM) databases from each of the NZTA regions. The Data Warehouse includes asset data for the entire New Zealand State Highway network since 1992, with the circa 11,000 km network separated into short (typically 100m length) segments of carriageway. The data used for this study is for the year 2009/2010.

The Data Warehouse records roughness in NAASRA counts. The IRI roughness is then estimated from the NAASRA counts using the following conversion, reported in the EEM (5).
\[ \text{NAASRA counts} = 26.49 \times \text{IRI} - 1.27 \]  

(1)

Where

\textbf{NAASRA counts} is reported in counts/km.

\textbf{IRI} is the International Roughness Index reported in m/km.

The above conversion appears to be supported by other publications. Prem (17), for example, stated that “there is a very good correlation between IRI and NAASRA Roughness Counts with 1 m/km of lane IRI corresponding to about 26 NAASRA counts”.

\textbf{Additional VOC due to Roughness}

The additional VOC due to roughness on each segment (VOC\textsubscript{RI}), over and above the base running cost, can be determined using Equation 2 below, adopted from the EEM (5). The regression coefficients, a to h, are vehicle classification and road category dependent. Values for the coefficients are included in Appendix A for reference.

\[ \text{VOC}_{\text{RI}} = \min \left( \left\{ \left( \frac{\text{RI}}{a + b \times \ln(\text{RI}) + c \times [\ln(\text{RI})]^2 + d \times [\ln(\text{RI})]^3 + e \times [\ln(\text{RI})]^4 + f \times [\ln(\text{RI})]^5] + g \right) \times \text{RI} + h \right\} \right) \]  

(2)

Where

\textbf{VOC\textsubscript{RI}} is the additional VOC due to roughness (cents/km).

\textbf{RI} is the maximum of either 2.5 or the roughness in IRI (m/km).

\textbf{ln} is the natural logarithm.

\textbf{a to h} are regression coefficients.

\textbf{Total VOC due to Roughness}

The total annual cost of travel on the network due to road roughness, VOC\textsubscript{total} can then be calculated by aggregating the additional VOC due to roughness, by road segment, for each vehicle classification. The calculation for each segment is based on the measured roughness of the road segment, Annual Average Daily Traffic (AADT), percentage of each vehicle type, and whether the segment is categorised as urban or rural. The VOC\textsubscript{total} (cents per annum) is represented using Equation 3 below:

\[ \text{VOC}_{\text{total}} = \sum_{\text{Segment 1}}^{\text{Segment m}} \left( \text{VOC}_{\text{RI}} \times VKT \right) \]  

(3)

Where

\textbf{VOC\textsubscript{RI}} refers to the additional VOC due to roughness value RI on the segment, for the particular vehicle classification given the road category of the segment (cents/km).

\textbf{VKT} refers to the annual VKT on the segment, for the particular vehicle classification (km/annum).
Segment (1–m) refers to the typically 100m long segments that the network data are recorded against.

Vehicle Type (1–n) refers to vehicle classifications such as Passenger Car or various categories of Commercial Vehicle.

The annual vehicle kilometres travelled (VKT) on each segment for a particular vehicle classification is calculated from the AADT on the segment, the length of the segment and percentage of each vehicle type on the segment.

VOC per Vehicle Kilometre Travelled

The total VOC due to roughness will be larger for networks with higher traffic volumes, all other things being equal, due to the cumulative nature of the calculation. Consequently, normalisation of the measure is required to allow comparison between disparate networks and, given that traffic growth will increase the total VOC year on year, to allow trend analysis over time. To normalise the calculation it is proposed to divide the total VOC due to roughness by the total VKT, for each network. This results in the average VOC due to road roughness per VKT and is termed ‘VOCi’ in this paper. The calculation is presented in Equation 4 below.

\[
VOCi = \frac{VOC_{Ri(total)}}{VKT_{total}}
\]

Where

- \( VOC_{Ri(total)} \) refers to the total VOC due to roughness for the network (cents/km)
- \( VKT_{total} \) refers to the total VKT on the network (km/annum)

The VOCi is effectively a mean value per VKT. When performing statistical analysis of the VOCi data it is important to weight the VOCi on each typically 100m segment by the VKT on that segment. Effectively each VKT can be considered a single occurrence of the VOCi for that VKT. A link with higher VKT has a greater influence on the VOCi, and should similarly have a greater influence on, for example, any percentile values that are output from the data.

It may also be necessary to baseline the costs to a specific base year, as new vehicle and fuel technology may change the VOC over time. This could be done by using the current costs as the basis, as the absolute value of VOC is not so much of interest as the relative measure of VOCi, in assessing the relative performance of each region.

NETWORK PERFORMANCE REPORTING

State Highway Classification System

NZTA recently developed a new State Highway classification system, which allocates routes to “categories based on the functions they perform”. The categories are based on seven criteria including Annual Average Daily Traffic (AADT), freight movement, population centres and port locations. These functional categories, in decreasing order of importance, are as follows:

- National Strategic – High Volume;
- National Strategic;
- Regional Strategic;
- Regional Connector; and
Regional Distributor.

NZTA further intends to develop “road user experience or levels of service” that are “appropriate for each category of road”. One of these levels of service is likely to be the expected level of maintenance. NZTA then intends to “work towards all the highways in a particular category offering a consistent level of service to users”.

Performance Reporting by Functional Classification

Figure 2 displays a box plot of the VOCi (cents/VKT) distribution for the whole New Zealand State Highway network, for each of the five functional classifications. The horizontal bar represents the VOCi, which is effectively the mean of the distribution. The top of the “box” represents the 75th percentile and the bottom of the box the 25th percentile. A number of things are immediately evident from the data, including the highly skewed distributions and the long distribution tails - maximum values are all greater than a VOCi of 20. The minimum, mode and 25th percentile of the distributions are all negligible, with the same true for the 75th percentile of the National Strategic – High Volume classification.

What is also evident from Figure 2 is that, as the functional importance of the classification decreases, from National Strategic – High Volume through to Regional Distributor, there is a corresponding increase in both VOCi and variability in the data. This is consistent with appropriate stewardship of the asset, whereby higher levels of service are applied to functionally more important routes on the network.

The maximum values, and hence tails of the distributions, are all extremely high, identifying those sections that account for the majority of VOC per VKT. Detailed analysis of the raw data shows that for National Strategic – High Volume, 84% of VKT are at a VOCi of 0; the whole VOCi of 0.12 is therefore generated by the “roughest” 16% of VKT. For the other classifications the whole VOCi is generated by between the roughest 33% and 44% of VKT. While the maximum values are very high, it is noted that for all classifications, less than 0.4% of VKT are at VOCi greater than 10.0.
Figure 3 and Figure 4 display, for two example regions, the VOCi by functional classification. The national VOCi are also included for comparison, along with total VKT for information. The intention here is to demonstrate that the national State Highway network trend of increasing VOCi with decreasing functional importance is not necessarily reflected in all the regions.

Figure 3 shows that the VOCi for all State Highway classifications in North Canterbury are close to or lower than the national average. VOCi is also similar between classifications, with VOCi on the less strategically important roads being lower than the national average. In comparison, Figure 4 shows that while the VOCi for the majority of Central Waikato’s functional classifications are comparable with the national average, the VOCi for its National Strategic road network is almost triple the national average.
Performance Comparison between Regions

Figure 5 displays the VOCi for all State Highway regions by functional classification. This plot allows for a comparison between regions for each classification. It also allows for comparison of VOCi by classification within a particular region, thereby indicating whether the higher classified routes are being maintained to a higher level and vice versa.

Looking across the regions it is evident that a number of the regions do not maintain their national strategic routes to a higher level than their regional routes, using VOCi as an indicator. Comparison between the regions also identifies, as expected, the network maintained by the Auckland Motorway Alliance as the best served and, at the other end of the scale, Gisborne as the worst served region, using VOCi as an indicator. It should, however, be noted that Gisborne’s relatively high roughness, and corresponding VOCi, can at least in part be attributed to the challenging topography in the region, and the resulting winding and rolling geometry of the network.

Figure 6 through to Figure 8 show, for selected functional classifications, the VOCi for each region. VKT is also provided for information and the regions are listed in order of increasing VKT. Immediately evident is the increase in both VOCi and variability in VOCi, with decreasing functional importance.

Figure 6 displays the VOCi by region for National Strategic – High Volume routes, sorted by VKT. Points of note include the significant VKT on the Auckland Motorway Alliance network and correspondingly low VOCi. Interestingly, the Performance Specified Maintenance Contract (PSMC) 005 has a comparably low VOCi but has significantly lower VKT on their network. The form of contract, and incorporated performance measures, are almost certainly responsible for this disparately high performance.
Figure 7 displays the VOCi by region for Regional Strategic routes, sorted by VKT. There is a significant negative relationship between VKT total and VOCi; as sub-network VKT total increases, VOCi generally decreases. This is the only dataset of the five functional classifications which shows a significant correlation at the 5% level of significance (P value is 0.015 for a paired t-test in this instance). Such a relationship is desirable given the reality of constrained budgets coupled with the Ministry of Transport’s desire to “lower the cost of transportation”; and may be considered to represent appropriate stewardship of the asset.
Figure 8 displays the VOCi by region for the lowest classification roads, Regional Distributor routes, sorted by VKT. Variability between regions is quite noticeable at this stage with the high VOCi for Gisborne, previously noted, again evident.

DISCUSSION AND CONCLUSIONS

Given the Ministry of Transport’s desire to “lower the cost of transportation” through the use of the National Land Transport Fund, performance monitoring of state highway maintenance practice should, ideally, be informed by VOC due to pavement roughness. Other surrogates do exist in the form of IRI and STE; however, neither account for the traffic mix or the fact that VOC increases with increasing IRI. In addition, the former ignores the VKT, a significant part of the VOC calculation, and the latter ignores the full distribution of roughness values. The proposed new index, VOCi, addresses these weaknesses and provides a much more targeted indicator of opportunities to “lower the cost of transportation” through maintenance. However, if VOCi is to be used as a KPI it would also be necessary to baseline costs, to enable relative comparison year on year.

Network reports have been produced for the entire State Highway network in order to demonstrate the application of the VOCi. These reports are broken down by functional classification and region. At the national level, the VOCi increases as the functional importance of the classification decreases, as indeed does the variability of the data. This is consistent with appropriate stewardship of the asset, taking account of the relative functional importance of the route, as reflected in the level of service provided. However, the same relationship does not always exist at the regional level, with some regions reporting VOCi that do not always adhere to the relative functional importance of the categorisation. Such information will be key in informing NZTA’s intention to “work towards all the highways in a particular category offering a consistent level of service to users” (18).

However, the VOCi data itself cannot provide definitive reasons for the variability between regions or within regions. For example, a relatively new, or newly rehabilitated, stretch of regional road could skew the network values for VOCi if the road accounts for a significant proportion of the regional
classification routes in question. Such a situation could, for example, result in the average VOCi for the regional classification being lower than the national classifications. Similarly, geological factors, climatic influences and topography could influence IRI, and therefore VOCi values, in some regions. Clearly, the VOCi, like any other indicator of its kind, is only part of the information available to decision makers and will not negate the need to “drill-down” to determine if there are any underlying reasons behind uncharacteristic values. This has been illustrated in the Gisborne region where the challenging topography and resulting geometry are at least in part responsible for the relatively high IRI and resulting VOCi values.

RECOMMENDATIONS

The NZTA rely on a suite of performance indicators to inform funding decisions. It is recommended that the VOCi is added to the annual reporting of network performance, thereby forming part of the information available to decision makers. This will allow the NZTA, where appropriate, to target funding to those parts of the network where it will lower the cost of transportation, thereby promoting effective funding decisions. This would also allow maintenance or renewal programmes to be targeted at areas that are inconsistent with their categorisation, to work towards the vision of a consistent level of service as measured by VOC due to roughness.

It is further recommended that the VOCi is incorporated into RAMM, to assist asset managers in selecting treatment lengths for maintenance that will lower the average cost of transportation on the network, as opposed to lowering the average IRI (i.e. worst first). In determining priorities, however, the VKT on a section also needs to be taken into account so that the decrease in transportation cost, due to a decrease in roughness, is maximised. Consequently, the VOC_{total} should also be reported.

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REFERENCES


**APPENDIX A: Additional VOC due to Roughness – Regression Coefficients (July 2008)**

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*It should be noted that the Economic Evaluation Manual contains a misprint for the Rural, Passenger Car (PC) regression coefficient "c". The value should be "-1224.6", as shown, rather than the "-224.6" included in the Manual.*