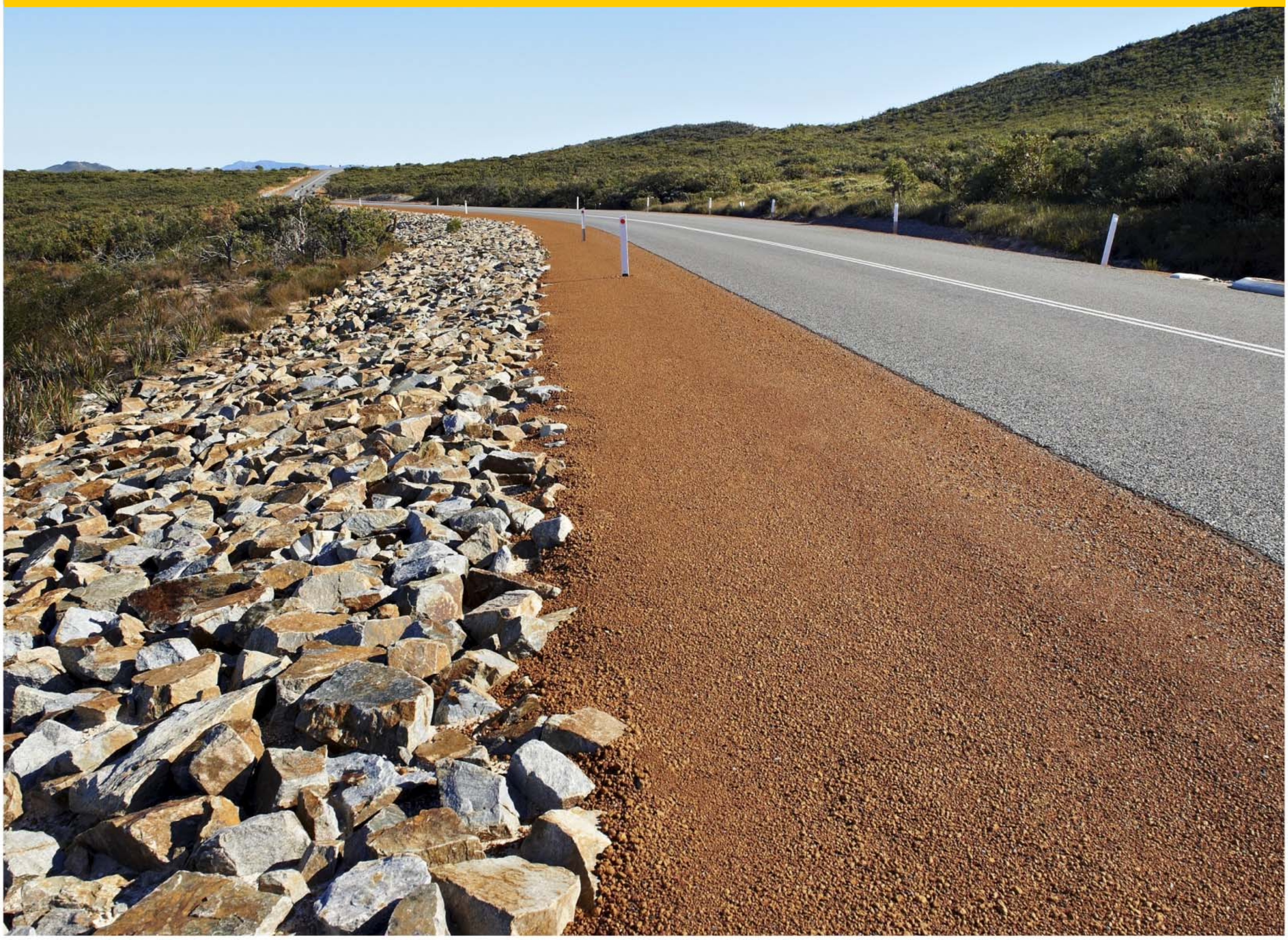
WAPARC

Western Australian Pavement Asset Research Centre

Composite Indicator for Whole of Life Management

2011/12



WAPARC Research Project (2011/0012) Composite Indicator for Whole of Life Management Final Report

Final Draft

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Overview of the research project

Main Roads WA (MRWA) is the agency responsible for building and maintaining the State's road network to ensure it delivers required levels of service at an appropriate cost. In order to provide assurance to their stakeholders concerning management of this network, MRWA has developed a performance measurement system. Performance measurement systems are generally considered to have three key elements (Neely et al. 1997):

- Individual indicators that quantify decisions and actions.
- A composite indicator that summarizes overall performance.
- A framework to support data collection, sorting, and manipulating into performance indicators.

MRWA has, over the years, developed many individual indicators, 32 are reported in the "Our Scorecard" section in the Annual Report (2011). While a range of performance indicators are required to cover different aspects of an organisation's business it can be difficult for stakeholders to develop a view of how performance is evolving over time when individual indicators may move in different directions. This project explores the development of a composite indicator to assist in communication with stakeholders, particularly State Government representatives and other Agencies. A composite indicator is an aggregated index comprising individual performance indicators and can be useful as a tool for conveying summary performance information and signalling policy priorities (Jacobs et al. 2004). The potential development of a composite indicator that would allow Main Roads to track performance in optimising Whole of Lifecycle Costs (WOLCC) has been a subject of discussion for some time. Early work also identified the benefits of a two tier approach – 1) a composite for high level reporting comprised of 2) a suite of indicators that could be analysed at a lower level of granularity and provide information that could be used to drive change. Guidance on developing composite indicators in general is provided in (Jacobs et al. 2004; Nardo et al. 2005; Yehia et al. 2008). Limited work has been done on developing a road performance composite index and what has been done mainly pertains to a composite indicator for road safety (Hermans et al. 2008; Wegman et al. 2008; Yongjun and Hermans 2008; Gitelman et al. 2010).

This report presents three examples of how a composite performance indicator might be developed for MRWA and discusses the benefits and limitations of each approach. The recommended way forward is to use scalable indicators focussed on performance of the 'Road Safety', 'Road Management & Efficiency' and 'Maintenance' programs using measures that can be calculated at the smallest level of granularity (10m – SLK Level[1]) and then aggregated to any desired level (pre- and post-project, corridor, network, region, state). Alternative approaches are presented which focus on the use of existing indicators available in the annual report but a significant limitation is the availability of data at regional levels and for certain programs in some years.

The report commences with a section on performance measurement good practice. A summary of the composite indicator results of each method is then presented followed by details on each of the

[1] The Straight Line Kilometre is the primary system of linear measurement used in Main Roads to define the location of events along a road

approaches and their results. Finally there is a discussion on issues arising from the work and suggestions for next steps.

Background on Main Roads

MRWA is responsible for managing an 18,503km road network (2011). The network is divided into ten geographical regions, which have vastly different needs and operation conditions. MRWA's $41 billion asset base consists of roads, bridges, road signs and traffic devices however this paper considers only the management of roads. The two major stakeholders for MRWA are the State Government (government) and road users (customers). The State Government of Western Australia has identified four goals for the organization. To achieve these goals MRWA takes an outcome based program management approach with seven programs driven by five primary objectives. These are shown in Table 1.

Table 1: Goals, Objectives and Programs at MRWA (MRWA Annual Report 2012)

Government Goals	**Main Roads WA**	
	Objectives	**Programs**
Outcome Based Service Delivery	A safe road environment	Road Safety & Office of Road Safety
	Reliable and efficient transport of people and goods	Road Management & Road Efficiency
State Building – Major Projects	Facilitate economical and regional development	State Development
Stronger focus on the Regions	A well maintained network	Maintenance
Social and Environmental Responsibility	Improved community access	Community access

MRWA has adopted a management framework (RO&DS) that segments the road life cycle into five phases: Assess, Select, Develop, Deliver, and Operate and Maintain. In the context of optimising lifecycle costs, each of the phases offers opportunities to undertake activities that contribute to this goal as well as the achievement of the organisational objectives outlined in Table 1. Strategies are formulated through the programs shown in the right-hand column in order to deliver levels of service that meet the organisational objectives. The overall performance of MRWA management is a result of the strategies and their associated activities across all life cycle phases. An effective performance management system should allow a line of sight from the activities identified in the strategies, from strategies to the programs and from programs to organisational objectives.

Research Approach

There are many ways to construct a composite performance measure. The purpose of this research is not to proscribe a single approach but to explore the relative merits of different approaches. The intention is to stimulate discussion as to what one is trying to demonstrate by the single number and at what level (e.g. State, regional) and the sensitivity or insensitivity of the single number to potential impact factors. The focus in this report is primarily on establishing what data the composite indicator should focus on and why. Subsequent steps involving multivariate analysis, normalization to ensure equal impact of contributors and sensitivity would be part of follow on work once the aim of the indicator and the data sources are established.

One of the constraints we imposed on the project was that the raw data required for each indicator in the composite indicator should be currently available within MRWA as there was not time during the project to collect new data.

Three approaches to identifying data for the composite indicator are explored as follows.

1) a) An average of a set of performance indicators relevant to road management activities that can be calculated at 10 metre level and then aggregated to the state level
   b) A weighted set of indicators from (1a)
2) An average of all the corporate performance indicators in the Main Roads annual report
3) Indicators from 2) excluding those used solely for external reporting

In approaches 1a), 2 and 3 a straight average is used. The effect of weighting the average is examined in approach 1b). Weighting was done using the Analytic Hierarchy Process (AHP) which leverages the experience of MRWA asset management staff to rank the importance of each indicator using a pairwise comparison. Details are provided in Appendix 1.

For comparison each individual indicator is reported on a scale from 1 to 10. A number of challenges were encountered for measures in the Main Roads annual report that are not reported as ratios, for example 'Average Return on Construction Expenditure', 'Average $ cost of network management per million vehicle km travelled', 'Average $ cost of road network maintenance per lane kilometre of road network' and 'Black Spot location indicator'. There is general agreement that normalising the cost can be misleading, a lower number would indicate less money is being spent; this is not necessarily a good thing. Likewise a large number could indicate over-spend, under-budgeting or additional investment. Nevertheless in order to include these important individual indicators in the composite, normalisation is required. The process used for each of these indicators is given in Appendix 1. However, when looking at the indicators the reader is encouraged to focus on the change year on year and the differences between the regions rather than the absolute value of the indicator. These issues with normalisation do not affect the scalable indicators.

Finally some work was done as part of this project to explore the relationship between the indicators in approach 1 using factor analysis. Factor analysis results in a set of factor loadings between zero and one for each of the indicators. These loadings show how relevant each indicator is to the factors, a factor loading of close to one implies that the indicator is closely related to that factor. The selection of indicators is statistically valid if the indicators do not show any similarity or if it is clear that similar indicators have different conceptual meanings. One seeks to avoid having indicators that appear to be closely related as this may indicate a high level of redundancy in the indicator selection. The results of this are not included in this report but showed some interesting relationships that could be the subject of future investigations.

The following sections describe how each of the indicators is calculated. This is followed by a discussion section on interpretation, potential use and challenges.

Composite performance indicator based on scalable measures

Approach

Previous work on identifying road performance indicators undertaken by national bodies including Austroads (Austroads 2007; Austroads 2011), the National Cooperative Highway Research Program (Chase 2005) and researchers (Horak et al. 2001; Haas and Lounis 2009)) confirm that most performance measurement work has been on corporate level data ("top-down"). An example of a "top-down" indicator would be the 'average cost of road maintenance' which uses cost data from the corporate financial database and road length from data measured at the road scale. It is not usually possible to assign corporate indicators such as cost to a specific section of road. In contrast, indicators used in operational decision making are calculated using the "bottom-up" approach. Examples of bottom up indicators which use data measured at the road scale (and aggregated to corporate level) are '% travel on roads meeting investigatory criteria' and '% Smooth Travel Exposure'. There can be challenges in seeing the relationship between changes in the value of performance indicators at the road level scale and the movement of corporate indicators.

This section focuses on data extracted from the Main Roads Integrated Road Information System (IRIS); a stable and consistently available corporate data source. It describes the development of individual scalable indicators based on data available at the SLK level which can then be formed into a composite indicator and aggregated to project, corridor, network, regional and state levels as required.

In order to develop trial scalable performance indicators the following criteria are used.

1. The individual indicator measures the activity or outcome of one of the three MRWA's asset management related programs of safe road environment, reliable and efficient transport, and a well maintained network.
2. The measure can be calculated from the link (SLK) to the network level allowing for indicators to be aggregated at a variety of levels, and
3. The indicator is measured consistently across the different regions of the network, and
4. There are an adequate number of data points to measure the state of the indicator, and
5. Each indicator can be linked to a cost in terms of $ or productivity to Main Roads or the Road Users.

The reader will note that because of criteria 1 there are no indicators for the 'Facilitate economical and regional development' or 'Improve community access and roadside amenity' programs. This is because these are corporate programs and data on them is not available at the SLK level. The same is true for the '% contracts completed' and '% community satisfaction' sets of indicators.

In order to satisfy these criteria, two new indicators have been developed and the scoring mechanisms for five existing indicators have been modified. These are summarised in Table 2 and described in more detail in the following section.

Table 2: Scalable indicators calculated at the SLK level, coloured by program

Programs	Indicator
Road Safety	Serious Crash (new)
Road Management & Efficiency	Availability to Freight (modified)
	Network configuration (modified)
Maintenance	Ride Quality (modified)
	Surfacing not beyond target age (modified)
	Roads not needing rehabilitation (new)
	Remaining life of pavement (modified)

Description of the Scalable indicators

Serious Crash - Effectiveness of Road Safety Strategies

This indicator aims to provide a measure of the effectiveness of our road safety improvements and strategies in reducing crashes. Reduced crash rate and severity both lead to reduced lifecycle costs as the community cost of fatal and serious injury crashes is very large. The indicator aims to show the extent to which the strategic goal of zero fatalities and serious accidents is met as well as showing the extent of the impact on the community as serious crashes (fatal + hospitalization) account for around 90% of the total crash cost. Willingness to pay figures have been used to weight crashes based on severity before crash rates are calculated and converted to a performance score out of 10.

Availability to Freight - Availability of the network to higher mass limit vehicles

Allowing the operation of more productive freight vehicles increases the efficiency of road transport by reducing transport costs. It also reduces the number of heavy vehicles required to move the same amount of freight thus reducing the number of trucks on our roads which has safety implications as well as potential benefits to wear and tear. Scoring is based on the proportion of the network available to restricted access vehicles (RAV). Scores are weighted according to maximum permissible mass as a ratio of total possible mass. It is recognised that there are limitations to this approach given that some roads will never be suitable for allowing the passage of RAV vehicles. but lack of data on this necessitates this simplified approach.

Network Configuration - Adherence to investigatory criteria

Investigatory Criteria (IC) ensure that carriageway and seal widths are not excessive and that horizontal and vertical geometry are appropriate for current and future traffic over the life of the road. The IC consider safety and capacity and are inherently based on optimising construction and maintenance costs against road user costs over the lifecycle of the road. Maintaining roads close to the levels prescribed by the IC therefore optimises agency and user costs and represents the lowest overall costs and ownership consistent with required levels of service for users. This criterion is based on the configuration criteria only (seal width, carriageway width, horizontal and vertical curve rating) and gives an indication of Main Roads ability to plan and maintain roads to desirable standards. Scoring for width criteria is based on ratio of actual widths to target widths and then weighted according to costs that would be incurred (using current replacement cost values from MRWAs asset valuation model) to bring the road up to the IC levels.

Ride quality indicator

Smoother roads reduce the dynamic load of vehicles on the pavement and extend its life. Vehicle operating costs are also reduced for users in terms of fuel and maintenance costs. This indicator scores Main Roads ability to maintain pavements at roughness levels that optimise both agency and user costs. Scoring is based on how far actual roughness values deviate from target optimum roughness levels calculated as a function of traffic volume and speed.

Surfacing not beyond target age – Preventative Maintenance

Resealing prevents moisture from penetrating the base-course when the binder in the seal coat becomes brittle and cracks allowing the ingress of moisture. This can lead to rapid deterioration of the pavement and lead to expensive rehabilitation work that costs significantly more than a reseal. This indicator provides an indication of the extent that preventative maintenance of road pavements is being adequately undertaken by comparing how far the actual age of the seal deviates from a target maximum seal age. Scores are weighted using replacement cost values from MRWAs asset valuation model which gives more weight to expensive assets that have slipped below threshold values.

Roads not needing rehabilitation

Proactive maintenance reduces the need for costly rehabilitation and reconstruction thus providing the public with improved safety and mobility, reduced congestion and smoother, longer lasting pavements. This indicator aims to measure whether we are addressing pavements whilst they are still in good condition before the onset of serious damage which relates directly to the effectiveness of maintenance strategies. This results in less disruption to road users and improved safety and mobility hence also reflects performance in minimising user costs as well as minimising agency costs as the cumulative value of preservation is less than the cost of reconstruction and rehabilitation. Sections requiring rehabilitation are derived using established modelling procedures with relative costs per square metre for each treatment triggered used to score each section of road.

Remaining life of pavement

This measure provides an indication of the extent that corrective maintenance due to pavement failure is being adequately undertaken. Roads with a remaining service life of less than 1 year are likely the result of poor planning maintenance and are assumed to have reached terminal state. Service life is calculated based on configuration (when design exceeds capacity) and condition (roughness) with scores of 0 given to assets that have reached terminal state. Scores are then weighted by replacement cost when aggregated in order to give more weight to expensive assets that have reached terminal state. There is correlation between this indicator and the 'Roads not needing rehabilitation' indicator and further work is required to assess if this indicator adds any additional information or if it should be removed.

Linking the scalable indicator approach to a cost focus

A summary of how each indicator in the scalable set can be linked to a cost focus is given Table 3.

Table 3: How the new indicators relate to costs from the agency and road user perspectives

Component	Agency Costs	Road User Perspective
Adherence to Investigatory Criteria	Adherence to IC optimises construction and maintenance costs against road user costs	Appropriate levels of service are maintained for users and safety and capacity are balanced
Effectiveness of Road Safety Strategies	Poor safety performance leads to unplanned, reactive treatments and minor capital works	High cost of crashes to the community
Roads Not needing rehabilitation	Rehabilitation and reconstruction is expensive. The cumulative value of preservation is significantly less than the cost of reconstruction and rehabilitation.	Improved safety and mobility for road users Reduced congestion and disruption as a result of minor works Smoother pavements leading to reduced vehicle operating costs
Surfacing Not beyond target age	Not resealing in appropriate timeframe can lead to rapid deterioration of the pavement leading to expensive rehabilitation that costs significantly more than resealing	Rehabilitation is disruptive to road users – increased travel times, congestion
Availability of Network to Higher mass limit vehicles	Less trucks on the road result in less wear and tear on pavements however heavier vehicles may lead to more wear and tear.	Reduced transport costs resulting from more productive freight vehicles
Pavement Remaining Life	As per 'Roads not needing rehabilitation'	As per 'Roads not needing rehabilitation'
Ride Quality Indicator	Smoother Roads reduce the dynamic load of vehicles on the pavement and extend its life.	Vehicle operating costs are reduced for users in terms of fuel and maintenance costs.

Results

Figure 1 shows the composite indicator for WA (in red) and the contributions from the three programs (Road Safety, Road Management & Efficiency, and Maintenance) for the period 2009-2012. The spider chart in Figure 2 shows how the individual indicators that contribute to the composite indicator at the state level (WA) change year on year.

Figure 1: Scalable composite indicator (average of all contributors) and displayed by program 2009-2012

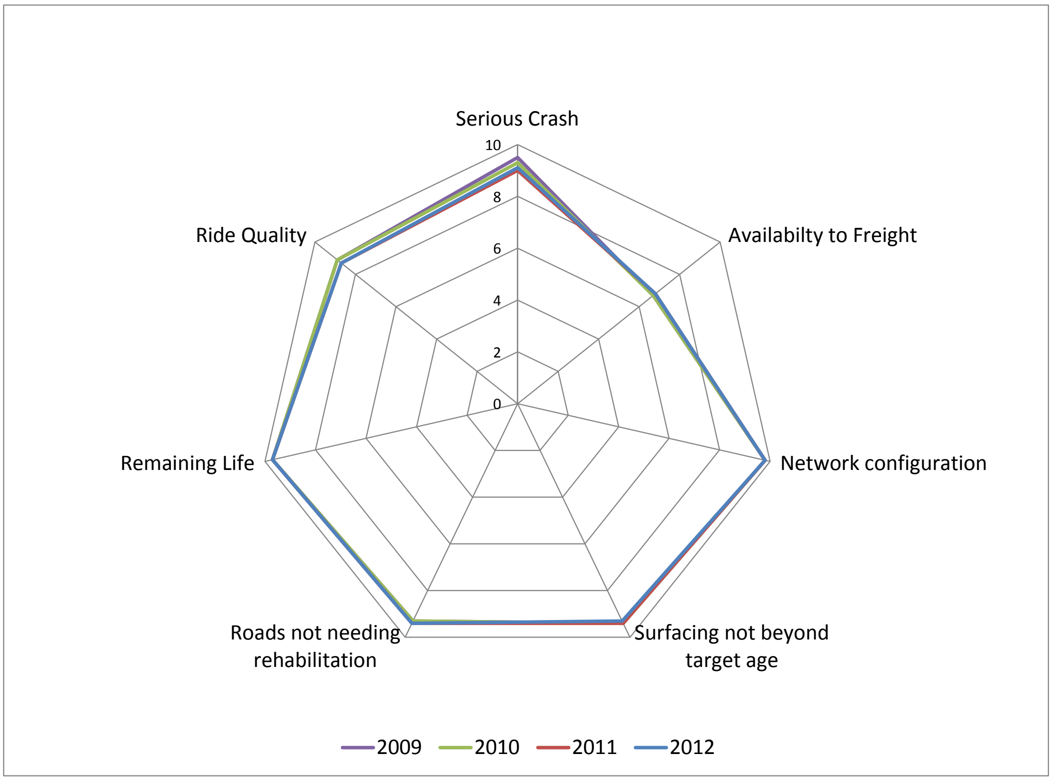


Figure 2: Scalable indicators WA 2009-1012

The composite indicator can be calculated at the regional level. An example of this is shown in Figure 3.

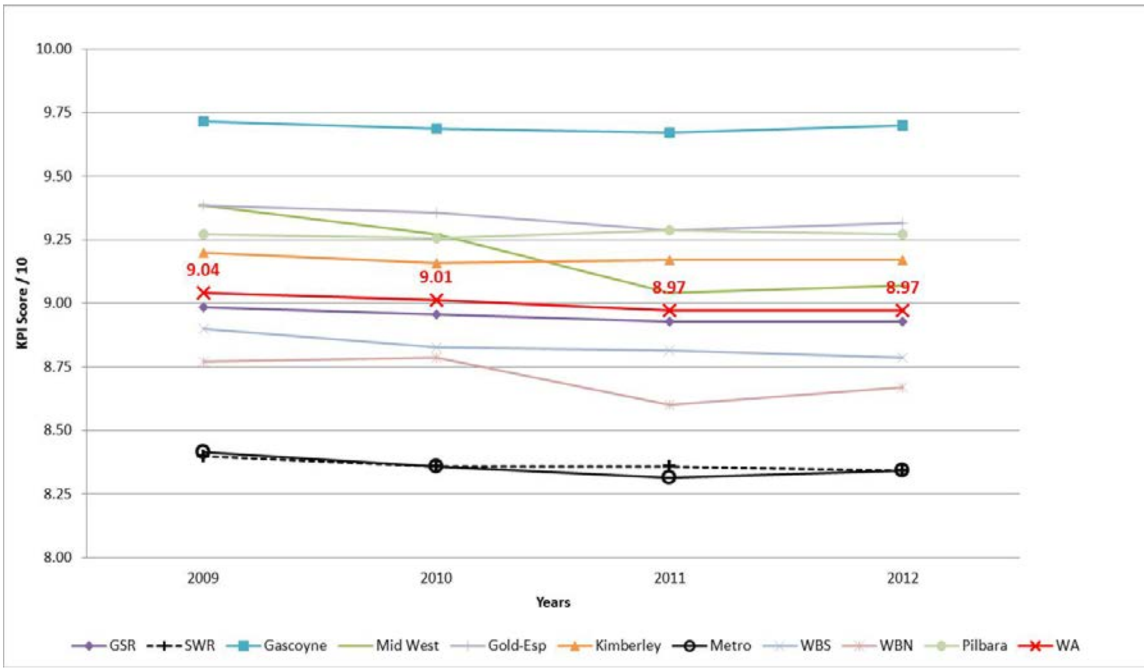


Figure 3: Scalable composite indicator by region for 2009-2012

The composite indicator can also be calculated at a project level. The Table 4 and Figure 4 below show the individual indicator scores and composite for a project that involved reconstruction of 1.3km of Indian Ocean Drive in Mid-West Region that was completed in 2011. There is a clear deterioration in the value of the composite indicator prior to the reconstruction work and an improvement afterwards.

Table 4: Individual indicator scores and composite for the Indian Ocean Drive Realignment project

Indicator	2009	2010	2011	2012
Serious Crash	10.0	10.0	10.0	10.0
Availability to Freight	2.8	2.8	2.8	2.8
Network configuration	8.3	8.3	8.3	10.0
Surfacing not beyond target age	8.0	6.9	5.6	10.0
Roads not needing rehabilitation	10.0	10.0	10.0	10.0
Remaining Life	6.6	6.6	6.6	10.0
Ride Quality	10.0	10.0	10.0	10.0
Average Composite	8.0	7.8	7.6	9.0
AHP Weighted Composite (see section below)	8.7	8.5	8.3	9.6

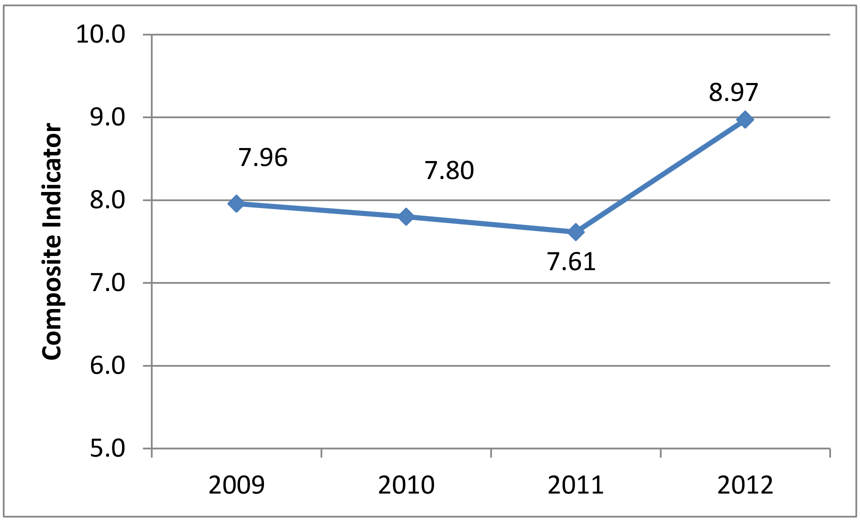


Figure 4: Scalable composite indicator 2009-2012 pre and post Indian Ocean Drive Realignment

The effect of alternative weightings for calculation of the composite was explored using the Analytic Hierarchy Process described in Appendix 1. The aim was to determine if professionals within the MRWA Asset Management branch felt that some indicators are of higher relative importance than others and should therefore be weighted accordingly. The results of this weighting exercise are shown in Table 5. It only involved a small number of professionals and is intended to be indicative of an approach that could be used and expanded if such weighting is deemed useful.

Table 5: Final weightings by indicator and by program.

Indicator	Indicator Weight	Program	Program Weight
Serious Crash	0.35	Road Safety	0.35
Network Configuration	0.14	Road Management & Efficiency	0.2
Availability to Freight	0.06		
Preventative Maintenance	0.17	Maintenance	0.45
Rehabilitation	0.14		
Remaining Life	0.08		
Ride Quality	0.06		

The effect of utilising these weightings on the values of the composite indicator and the contributions of each program to the composite indicator is shown in Figure 5.

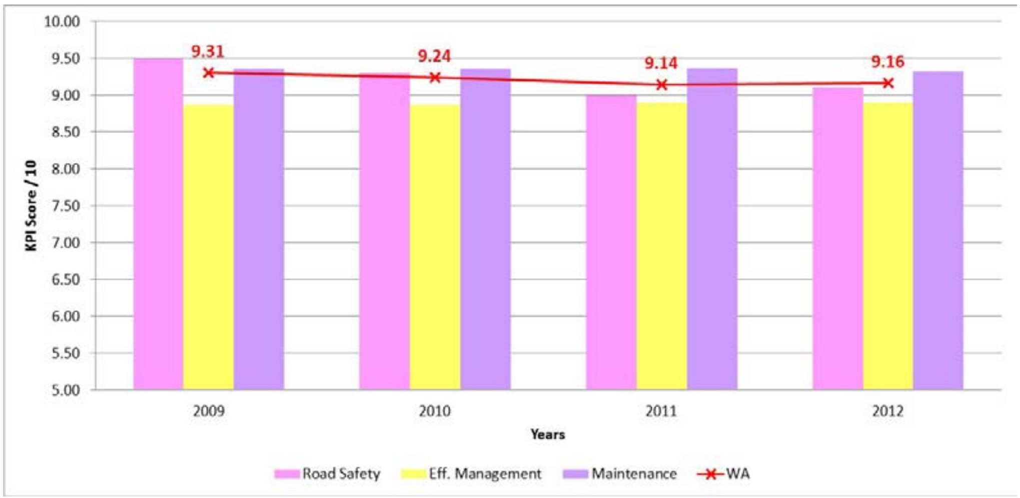


Figure 5: Scalable composite indicator (weighted average of all contributors) and displayed by program 2009-2012

Observations

1. The composite indicator for the State level is stable over the period 2009-2012 and variance is very low (Figure 1).
2. Program contributions to the composite indicator at the State level are also invariant (Figure 2).
3. Calculation of the composite indicator at the Regional level provides some insight into the relative performance of the regions and how this has changed over time. This may be a useful as a starting point for discussions about what is driving the composite indicator value and changes in the different regions.
4. The value of being able to calculate a composite indicator at different scales becomes apparent when looking at the data for a specific project, in this case the Indian Ocean Drive realignment project. The overall deterioration of the road prior to the work can be tracked through movement of the composite indicator as can the improvement on completion of the project.
5. This composite draws raw data from a single data source ensuring that the indicator can be calculated at any time. This ensures consistency and repeatability in calculations and allows for historical values to be recalculated if the method changes.
6. This composite indicator focuses on the performance of the road network. Individual indicators that are only available at the organisation or regional levels cannot be included in this composite indicator. Neither are those that assess performance against the organisational outcomes “facilitate economical and regional development” and “improve community access and roadside amenity” as they are not available at the SLK level.
7. Scoring of the individual indicators has been able to be designed to reflect a cost component where possible which better aligns with the original intention of the project to measure Main Roads performance in optimising lifecycle costs.

Composite State performance indicator calculated using all organisational indicators

Approach

This approach takes the data presented for each of the five outcome areas from the Main Roads annual report and calculates a composite value based on normalising of the data and taking an average. The indicators in the annual report are shown in Table 6.

Table 6: Organisational indicators from the Main Roads Annual report, sorted by program

Programs	Indicators from the MRWA Annual Report	
Road Safety	Black Spot location indicator	
	% community satisfaction with road safety	
	% Road Safety Projects (RSP) contracts completed on time	
	% RSP contracts completed on budget	
Office of Road Safety	% effectiveness of safety awareness campaigns	
	% Office of Road Safety (ORS) projects completed on time	
	% ORS projects completed on budget	
State Development	Average return on construction expenditure	
	% State Development contracts completed on time	
	% State Development contracts completed on budget	
Community Access	% of year that 100% State Road Network available	
	% Community satisfaction with cycle/pedestrian facilities	
	% Community Access contracts completed on time	
	% Community Access contracts completed on budget	
Road Management & Efficiency	% road network permitted for use by heavy vehicles	B Doubles
		Double R T <27.5m
		Double R T <36.5m
		Triple R T
	% travel on roads meeting investigatory criteria	Roads
		Bridge Strength
		Bridge Width
	Average $ cost of network management per million vehicle km travelled	
	% Community satisfaction (overall)	
	% Efficiency Program contracts completed on time	
	% Efficiency Program contracts completed on budget	
Maintenance	% Smooth Travel Exposure	
	% Preventative Maintenance Indicator	
	Average $ cost of network maintenance per lane kilometre of network	
	% Community satisfaction with road maintenance	
	% Availability of traffic signals, lighting and emergency phones	Traffic signals
		Lighting
		Phones

Results

Figure 6 shows the average (composite) performance of WA (red line) over the period 2008-2012 based on an average of all the individual contributions shown in Table 6. The Figure also shows the contribution to the composite value from each of the program groups.

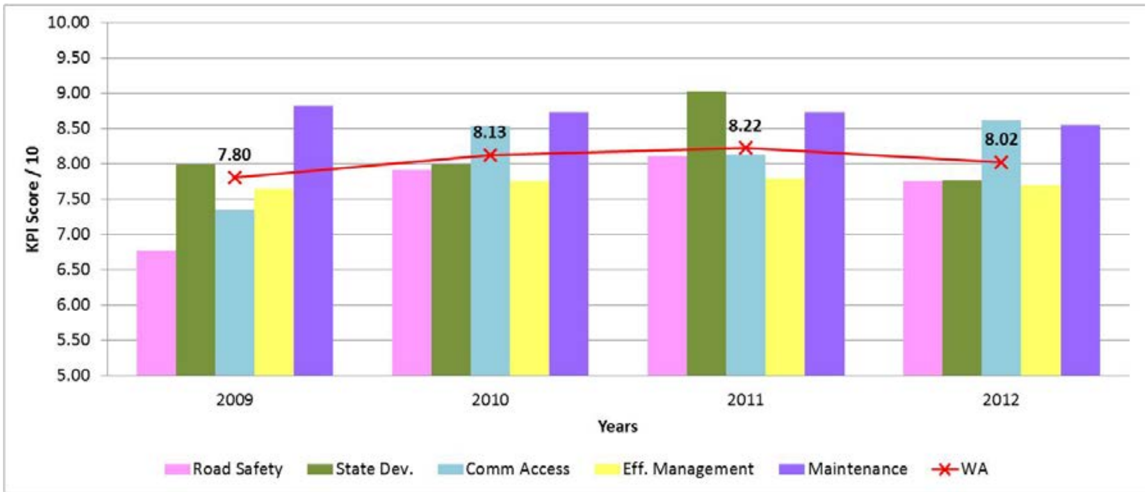


Figure 6: WA Composite indicator (shown in red) for all organisational indicators and contributions by program group 2009-2012

Figure 7 provides a summary of the performance of the 32 individual indicators reported in the Annual report over the period 2009-2011. The data for each year represents an average of the data for each region in each year where it is available[2].

In the spider chart in Figure 7 each contributing indicator is given as a score between 1 and 10. For most of the indicators in the annual report values are given in percentage and these appear as-is in the Figure. However where performance indicators are reported as a number, for example 'Average $ cost of network maintenance per lane' values, a process to normalise the value to a 1-10 scale has been developed. These processes are described in Appendix 1. The reader is reminded that there are a number of ways to normalise the data and the methods provided are just examples of what is possible. Indicators for which a normalisation process has been applied are: Black Spot (used in the following section), Average $ cost of network maintenance per lane, Average $ cost of network management per million vehicle kilometres travelled, and Average return on construction expenditure.

[2] The Office of Road Safety measures were not available in 2009 and so are not included in the 2009 Road Safety Average

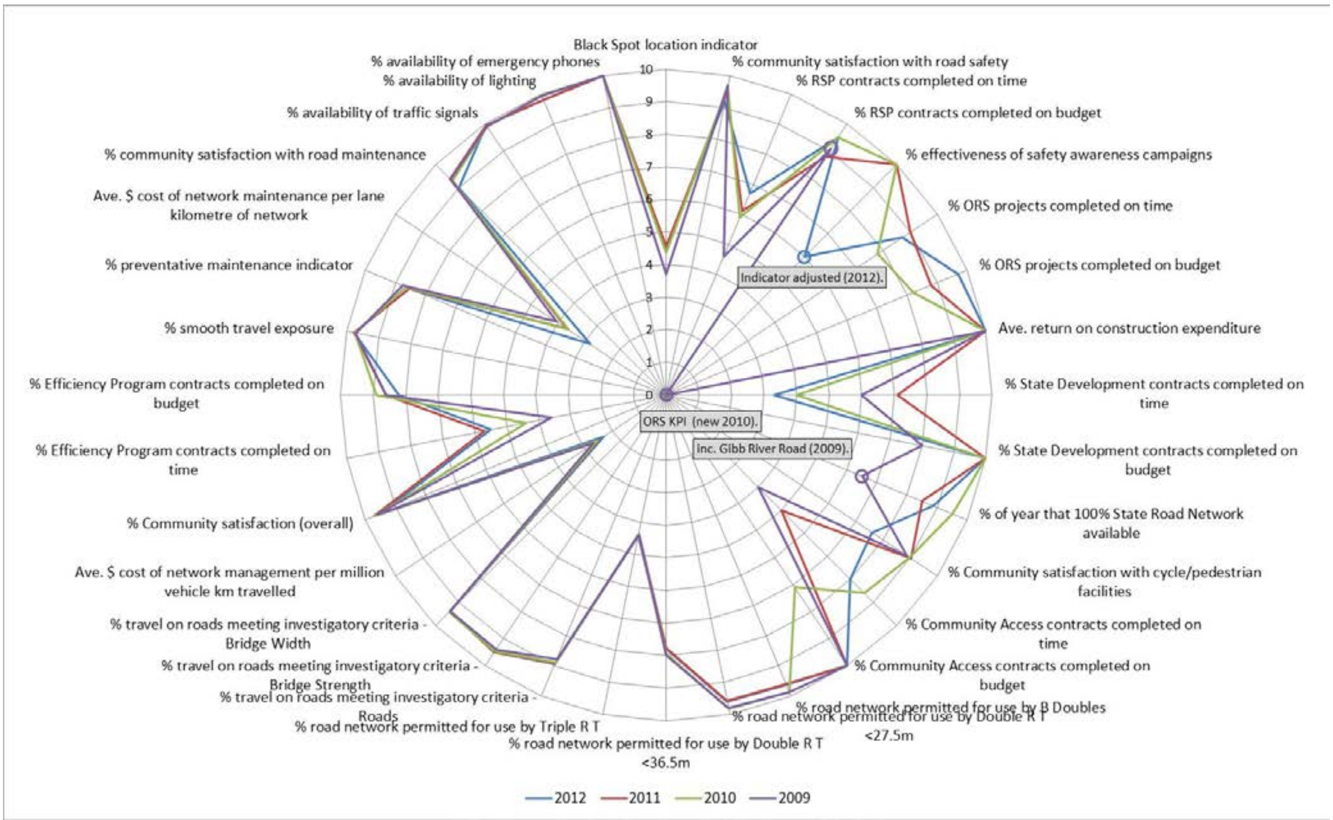


Figure 7: Annual report Indicators for WA 2009-2012

Observations

1. Movement of the composite indicator based on all the indicators from the annual report is shown in Figure 6. There is slight movement year on year (average 2.5%) of the composite value.
2. The movement of the individual indicators in the period 2009-2012 can be used as the basis for questions such as show some interesting patterns as follows:
    a. Why are the values for 'contracts completed on budget' always significantly higher than the values for 'contracts completed on time'? (Refer to indicators for Efficiency, Road Safety and State Development programs).
    b. Why has there been such a big change in effectiveness of safety awareness campaign values? In this case it is due to changes in how the indicator is calculated.
    c. Why was the value for '% of the year that 100% of the State Road Network is available' so much lower in 2009? This was due to closure of the Gibb River Road.
3. The issues described in 2. are illustrative of the challenges with using corporate indicators which cannot be recalculated as methods change and may be sensitive to large swings due to individual events.
4. Figure 8 shows how the composite indicator based on measures from the annual report can be calculated and displayed at the regional level however it is misleading as is obvious from observing that the WA average (red line) is higher than the contributions from the regions. This is because the WA average is based on 32 contributing indicators but in the regions between 8 and 10 of these indicators may not have a value in a single year. For example in 2012 there are

no values for Office of Road Safety metrics, Efficiency Program or Community Access program data for any of the regions. However there are some data for these programs at the regional level in other years.

5. Because the composite indicator based on all the annual indicators cannot be reliably decomposed into its constituent elements it is of limited value for analysis.
6. The indicators reported in this composite contain both external and internal indicators. All external indicators have been signed off by Program Managers, Executive Directors, Corporate Executive, Office of the Auditor General (OAG) and Treasury. The internal indicators are approved and signed off by the Corporate Executive. The documentary evidence is revisited annually within the KPI Manual in that each Executive Director is required to sign off on the results, methodology and by inference the fact that they remain relevant. However they can and do evolve.

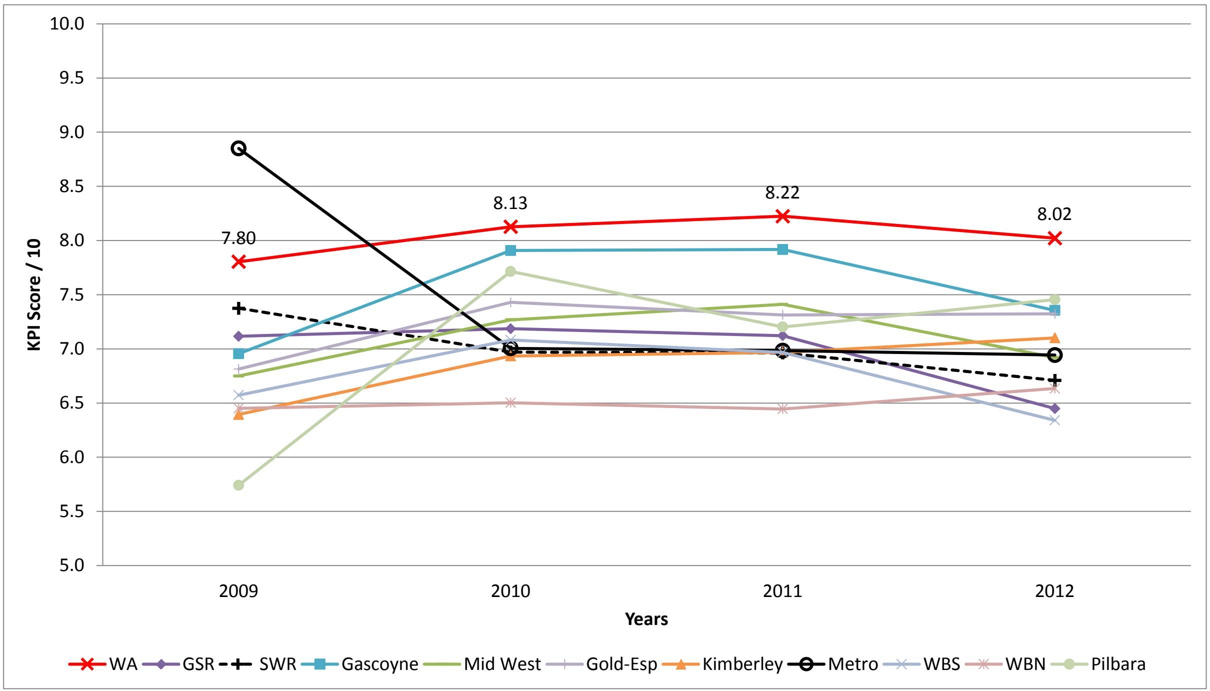


Figure 8: Composite indicator values for the regions calculated using the MRWA Annual Report measures 2009-2012

Composite State performance calculated using internal organisational indicators

Approach

The internal KPIs are not subject to the same rigour of external KPIs however they do form part of the Corporate Business Plan which is signed off annually by the Committee on Business Improvement (BIC) and Corporate Executive. This approach takes the internal indicators for each of the five outcome areas from the Main Roads annual report and calculates a composite value based on normalising of the data and an average. They are essentially a subset (10) of those reported in the previous section.

The indicators are shown in Table 7.

Table 7: Internal organisational measures for the five program areas

Programs	
Road Safety and Office of Road Safety	Black Spot location indicator
	% effectiveness of safety awareness campaigns
State Development	Average return on construction expenditure
Community access	% of year that 100% State Road Network available
Road Management & Efficiency	% Road network permitted for use by heavy vehicles
	% Travel on roads meeting investigatory criteria
	Average $ cost of network management per million vehicle km travelled
Maintenance	% Smooth travel exposure
	% Preventative Maintenance indicator
	Average. $ cost of network maintenance per lane kilometre of network

Results

Figure 10 shows the average (composite) performance of WA (red line) over the period 2009-2012 based on an average of the 10 internal organisational measures shown in Table 7. The Figure also shows the contribution to the composite value from each of the program groups. Please note while it appears that there is no contribution from Road Safety in 2009, there is a small value <5. The y axis has been scaled 5-10 for consistency with the other graphs.

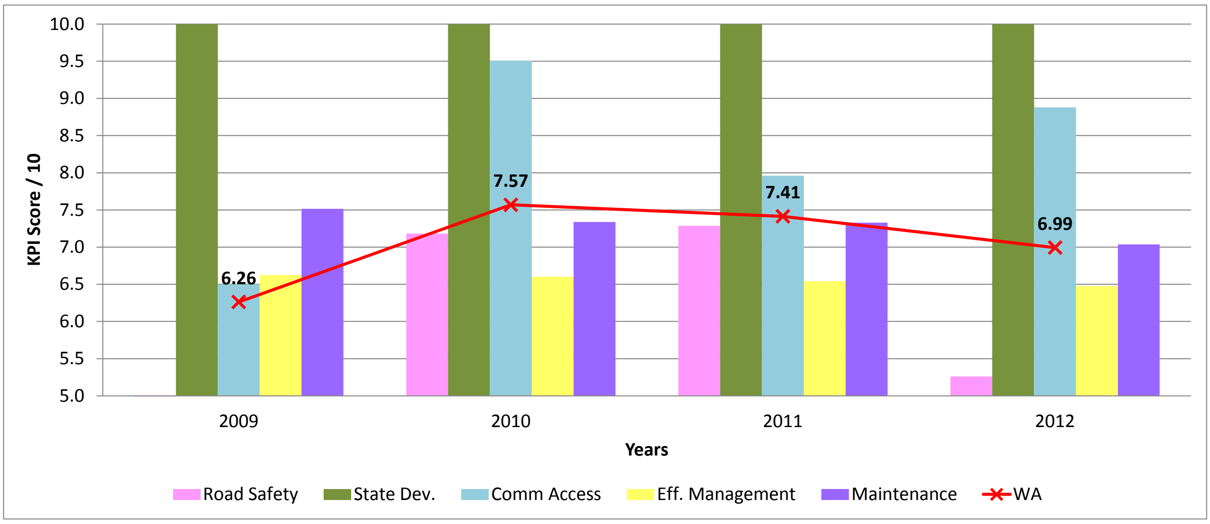


Figure 9: WA composite indicator (shown in red) for internal indicators and contributions by program group 2009-201

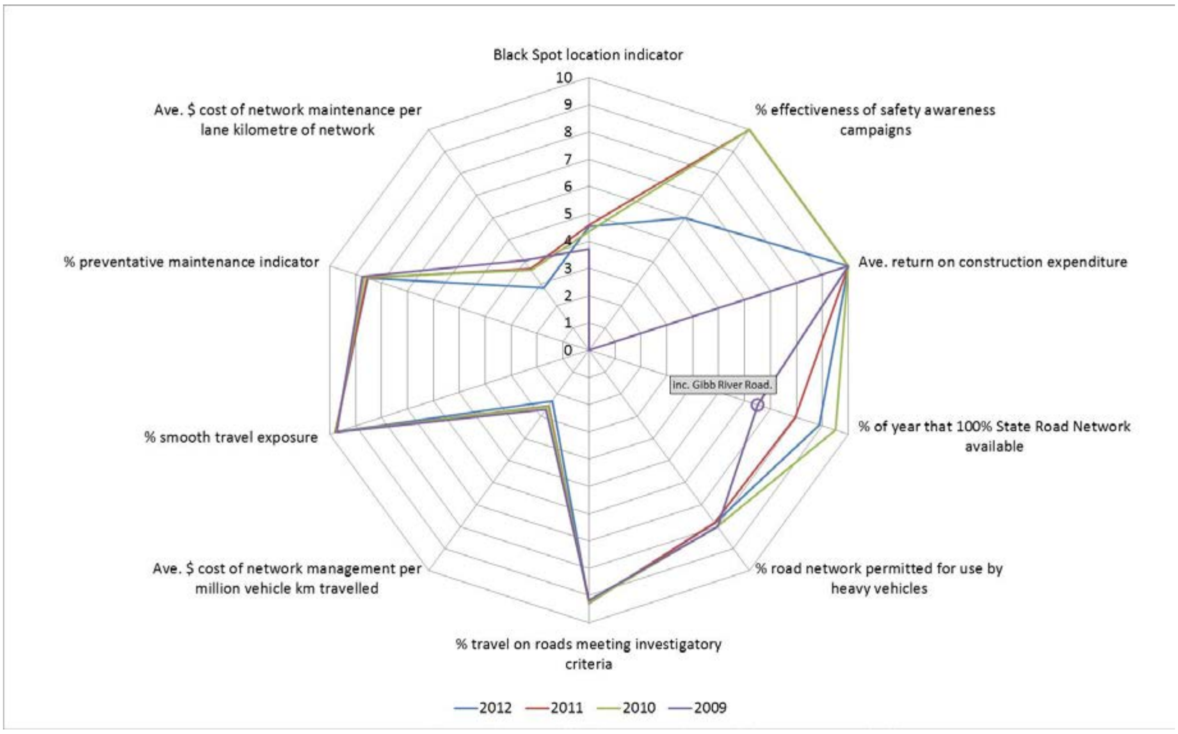


Figure 10: Internal indicators from the annual report 2009-1012

As with the previous 'All indicators' approach it is possible to examine data at the regional level. An example of this using the bar chart is shown in Figure 11 below. Once again, the composite value calculated at the WA level (red) is not the average of the regions as many of the regions did not have projects such as Office of Road Safety, State Development or Community access projects in certain years which skews their averages.

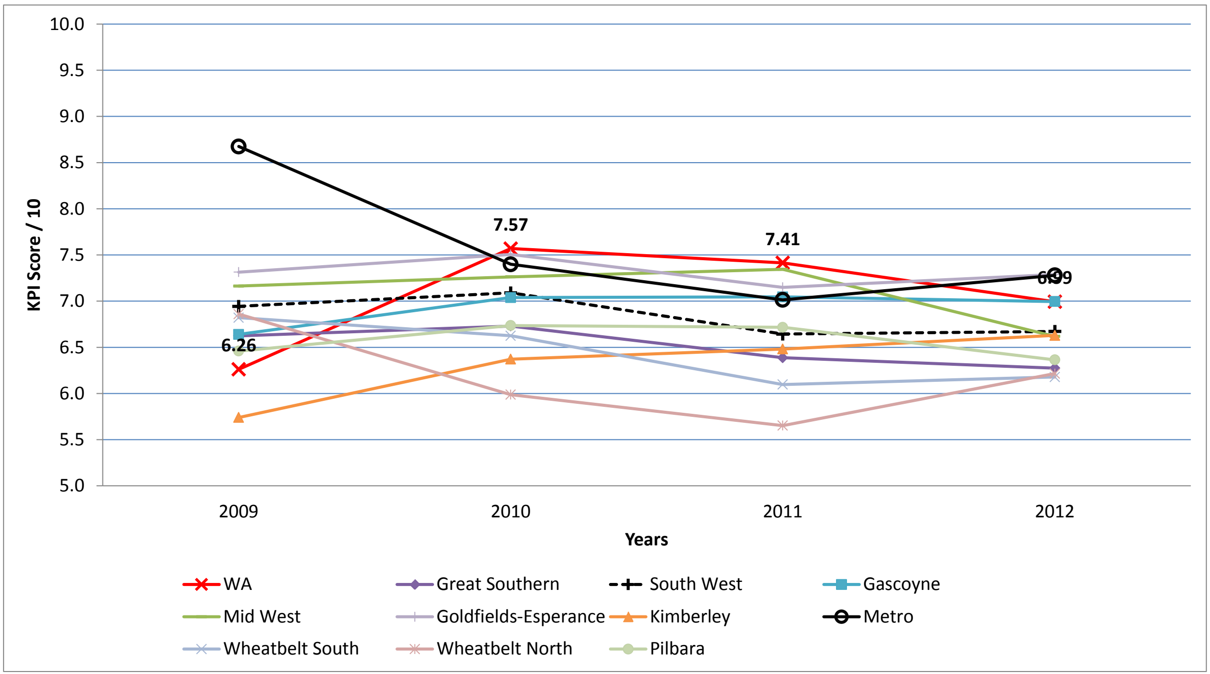


Figure 11: Internal indicators at the regional level by year

Observations

1. Movement of the WA composite indicator based on a reduced set of 9 internal indicators from the annual report is shown in Figure 9. There is greater movement year on year (average 9.6%) of the composite value than for the all-indicator set shown in the previous section.
2. It can be seen in the spider chart in Figure 10 that the movement of the WA composite is largely governed by wide variations in two contributions, '% effectiveness of road safety campaigns' and 'average return construction expenditure'. Both of these have variations due to data rather than due to underlying performance issues.
3. As with the earlier example Figure 11 shows how the composite indicator based on measures from the annual report can be calculated and displayed at the regional level however it is misleading as is obvious from observing that the WA average (red line) is higher than the contributions from the regions. This is because the regions do not have entries for a number of the indicators which skews their averages.
4. Because the composite indicator based on all the annual internal indicators cannot be reliably decomposed into its constituent elements it is of limited value for analysis.

Discussion

Discussion of results

A single number can be calculated in many different ways as shown through examples of the different approaches in Table 8 below. Approaches 1a and 1b are "bottom-up", the composite scalable indicator is constructed from 7 indicators calculated at the SLK level and amalgamated to the State level. The difference between 1a and 1b is that the latter is weighted to reflect the perceived relative importance of the three programs to optimising user and agency costs that contribute to the scalable composite indicator (Road Safety, Road Management & Efficiency, and Maintenance). Approaches 2 and 3 are "top-down" and calculate a composite based on indicators from the MRWA Annual Report. Approach 2 used all 32 indicators and approach 3 a subset of 9 indicators identified as key for internal users. It is important to note that regardless of the way the composite indicator is calculated, the absolute value is not the focus; it is how it changes over time and how the regions (and for the SLK smaller units such as corridors) contribute that is important.

Table 8: Comparing Composite Performance Indicator approaches for MRWA performance across the State

Approach to calculating composite performance indicator		**# indicators**	**Ability to calculate at different scales**	**2009**	**2010**	**2011**	**2012**	**Avg. % year on year variation**
1a	Composite scalable performance indicator based on measures at the **SLK scale**	7	Y	9.04	9.01	8.97	8.97	0.3%
1b	Composite scalable performance indicator based on measures at the **SLK scale weighted using AHP**	7	Y	9.31	9.24	9.14	9.16	0.5%
2	Composite State performance indicator calculated using **all organisational indicators**	32	N	7.80	8.13	8.22	8.01	2.6%
3	Composite State performance calculated using **internal organisational indicators**	9	N	6.26	7.57	7.41	6.99	9.6%

The Scalable composite indicator is the preferred approach for the following reasons:

1. The constituent elements of the Scalable composite indicator are aligned with a core goal of Main Roads which is to "provide safe and efficient road access" and there is a line of sight to the performance of the actual asset.
2. At the State level the Scalable composite indicator is stable (low variability year on year) however it is sensitive to changes at a Project level as shown by its response to work such as

the Indian Ocean Drive realignment project Figure 4. There is value in being able to see the impact of maintenance, construction or improvement works on each of the individual indicators and on the composite.

3. The Scalable composite can be calculated at the regional level without loss of fidelity in the averaging process. This was not possible with 2) or 3) based on the organisational indicators as a number of the contributing elements were not available for specific regions in specific years. This is particularly common for Efficiency Program or Community Access program data as each region does not necessarily have these programs each year.
4. The display of the scalable data at a regional level allows for questions to be asked about the relative performance of the different regions and how the value of their composite metric changes with time. This creates transparency and supports learning about what is done well and where improvements are possible. Both are important goals of performance measurement systems (de Bruijn 2007). Care should be taken in developing reward/ sanction depending on performance based on composite indicators as this encourages gaming of the system.
5. The Scalable composite is based on 7 indicators which are a mix of leading ('Adherence to investigatory criteria', 'Roads not needing rehabilitation', 'Surfacing not beyond target age' and 'Remaining life of pavement') and lagging indicators ('Effectiveness of Road Strategies', 'Availability of the network to higher mass limit vehicles', 'Ride quality'). If the leading indicators deteriorate we would expect availability and quality measures (lag) to rise. The organisational measures in the annual report are overwhelmingly lag indicators.
6. The Scalable composite does not contain any contributing performance indicators that are troublesome to normalise. For example, the movement of cost indicators either up or down depends on what one is trying to achieve, an increase/ or decrease is not predictably a good or bad outcome. Within the organisational composite indicators there are a number of cost and other contributors, such as Black Spot, that are problematic to normalise.
7. The Scalable data comes from a single source ensures that the indicator can be calculated at any time. This ensures consistency and repeatability in calculations. If the weightings change, a new performance indicator is added or the methodology for an individual indicator is changed, then the new composite indicator can be recalculated. This allows the calculation of the indicators to be dynamic and improve.

A comparison between how the scalable indicators are calculated compared their equivalent existing corporate indicator is in Appendix 3.

Future Work

There is further work to do on the individual and composite Scalable indicator as follows:

1. Although a preliminary check has been made on the individual indicators to ascertain that they meet the generally accepted principles of good practice in identifying indicators listed below(Hollnagel et al. 2011), time did not allow for a full investigation of c), d) and f). Investigating items c) and d) requires socialisation of the approach within the Main Roads community. Item f) requires further investigation into the behaviour of the indicators at the project and regional levels.
    a) Can the values of the indicators be rendered in a concise manner, either quantitative or qualitative?

b) Are the indicators well defined, reliable and valid?
c) Are the indicators objective (their interpretation is normative) or are they subjective (their interpretation depends on who looks at them)?
d) Are the indicators sufficiently sensitive to change, i.e. can the effects of a change be seen within a reasonable amount of time?
e) Are the indicators easy to use ('cheap') or are they difficult to use ('costly')?
f) Are the indicators aligned with objectives (line of sight)?
g) Are the indicators legitimate, that is, accepted by the party being measured?

2. There is a need to investigate the correlation/ independence of the individual performance measures using multivariate analysis. The authors suspect that there may be a relationship between the 'Roads not needing rehabilitation' and the 'Remaining life of pavement' indicator. The relationships between these, and other, contributing indicators needs more investigation. As part of this, some preliminary work was done using factor analysis. This explores how much the variance in the data can be explained by different factors. It is a commonly used tool in developing performance measures to examine potential relationships between indicators and to form composite indicators that capture as much common information about contributing indicators as possible(Gitelman et al. 2010). We strongly suggest that if the use of composite indicator is agreed on then further statistical investigation of its contributing elements be conducted.
3. At present, the relative value to the composite of an extra unit of attainment for an individual indicator is not equal across all the Scalable indicators. This would require some additional work involving the following steps, all quite achievable. These include a) understanding the distributions of each of the variables (skewed, normal etc.), b) developing thresholds to transform the continuous variables into categorical variables (on a 3 or 5 point scale) where the thresholds for deciding the cut-offs for each of these categories varies for each variable to ensure that the resulting transformed categorical variable has an approximately normal distribution, and c) developing a scaled score from the position on the distribution e.g. 1=1st quartile etc. This means all indicators end up as a score between say 1 and 5 and can be combined into the composite (Freudenberg 2003; Jacobs et al. 2004; Yehia et al. 2008; Gitelman et al. 2010).
4. The Scalable indicator approach uses data directly extracted from Main Roads Integrated Road Information System (IRIS) therefore issues of data integrity in IRIS will be important if the data is going to be actively used in the calculation of composite indicators. Of particular relevance is the need to update IRIS in a timely fashion at the conclusion of projects.
5. There is an evolving body of work on composite indicators for road safety measures (Hermans et al. 2008; Yongjun and Hermans 2008; Gitelman et al. 2010) of which a significant area of discussion has been in weighting. We have tentatively explored weighting in this project using AHP but there is more that can be done if this is deemed desirable.

Conclusions

Composite indicators are increasingly being used to measure the performance of organisations and institutions in economic, social and policy areas (Freudenberg 2003). Composite indicators integrate a large amount of information in a format that is easily understood and are therefore a valuable tool for conveying a summary assessment of performance in priority areas (Jacobs et al. 2004). Given the wide range of stakeholders that MRWA engages with, there may be value in being able to display performance using one composite rather than a suite of performance indicators.

The construction of composite measures is not straightforward and the project has demonstrated a number of different approaches to developing a composite indicator for Main Roads. A review of the results suggests that the approach that allows performance to be visualised at different levels from the SLK to the Regional and State network using a mix of lead and lag indicators is the most promising to move forward with. In order to do this a number of new measures or new ways of calculating individual indicators have been developed. These are described in the report and the performance of the network using the composite indicator is demonstrated at different spatial levels for 2009-2012. The composite indicator describes performance in the Road Safety, Maintenance, and Road Management & Efficiency program areas. Alternative approaches to developing the composite using indicators from the Main Roads Annual Report only allow display of performance at the State level, the composite indicator does not support like for like comparisons on the regional scale and cannot be used at smaller scales.

As part of this project there has been an emphasis on transparency in how the composite indicator is developed and why individual indicators were selected. Use and publication of composite performance measures can generate both positive and negative behavioural responses, so careful consideration needs to be given to their creation and subsequent use (Jacobs et al. 2004).

Acknowledgements

This work benefitted enormously from the visit by Dr Rob Schoenmaker from the Netherlands in August 2012. Dr Schoenmaker is an academic at Delft University of Technology and Senior Policy Advisor for the Dutch Rijkswaterstaat.

Appendix 1

The Analytic Hierarchy Process

Calculating the Weightings for the Composite Score

In order to calculate a composite score from the seven individual indicators from method 1b, the Analytical Hierarchy Process (AHP) was used to determine a preliminary set of weighting factors for each indicator. AHP is a process pioneered by Thomas Saaty in the 1980s that allows prioritisation of alternatives through a logical framework which requires participants to make pair wise comparisons of indicators and make an assessment of the relative importance of one over the other.

8 participants were surveyed. Each respondent's results were checked for consistency using Saaty's methodology of calculating an inconsistency ratio. As a rule of thumb, an inconsistency ratio of less than.1 is desired although 0.2 is often cited. In this instance, all respondents' surveys met this requirement and hence all were included in the final results. Table 9 show the individual priority weights of each of the respondents with respect to each of the seven indicators:

Table 9 : Priority weights of individual respondents

	R1	R2	R3	R4	R5	R6	R7	R8
Consistency Ratio	0.07	0.00	0.11	0.05	0.16	0.12	0.03	0.15
Serious Crash	0.26	0.03	0.22	0.31	0.13	0.45	0.08	0.42
Freight	0.03	0.08	0.03	0.02	0.05	0.02	0.16	0.07
Network Configuration	0.11	0.08	0.31	0.08	0.08	0.08	0.14	0.04
Preventative Maintenance	0.14	0.24	0.04	0.28	0.26	0.16	0.16	0.23
Rehabilitation	0.17	0.24	0.06	0.14	0.28	0.14	0.16	0.12
Remaining Life	0.26	0.08	0.06	0.14	0.02	0.12	0.16	0.06
Ride Quality	0.03	0.24	0.27	0.02	0.17	0.03	0.14	0.07

Four different aggregation methods were then used to synthesise the results.

1. Arithmetic Mean of individual priorities
2. Geometric Mean of individual priorities
3. Arithmetic Mean of individual comparisons
4. Geometric Mean of individual comparisons

Methods 1 and 2 involve calculating the average of each of the individual priority weights in the table above. Methods 3 and 4 involve recalculating the pairwise comparison matrix using the average score for each of the pairwise comparisons. Table 10shows the results achieved from each of these methods.

Table 10 Priority weightings from four different group aggregation methods

	Average of individual priorities		**Average of individual comparisons**	
	M1 arithmetic	M2 geometric	M3 arithmetic	M4 geometric
Serious Crash	0.24	0.18	0.35	0.34
Freight	0.06	0.05	0.06	0.06
Network Configuration	0.12	0.10	0.14	0.14
Preventative Maintenance	0.19	0.17	0.17	0.17
Rehabilitation	0.17	0.15	0.14	0.13
Remaining Life	0.11	0.09	0.08	0.07
Ride Quality	0.12	0.08	0.06	0.05

In terms of preferences, four of the eight respondents considered Serious Crash to be the most significant indicator. Interestingly, the only respondent that rated crash the least significant was the pavement expert. Four of the respondents considered preventative maintenance to be the second most important indicator. Six respondents rated the rehabilitation indicator as the third most important or higher. Freight was consistently considered the least or second least significant indicator.

The four aggregation methods showed no significant difference in overall ranking of indicators as shown in the table below:

Table 11 Priority Rankings of Four aggregation methods

	m1	m2	m3	m4
Serious Crash	1	1	1	1
Preventative Maintenance	2	2	2	2
Rehabilitation	3	3	3	3
Network Configuration	5	4	3	4
Remaining Life	6	5	5	5
Ride Quality	5	6	7	7
Freight	7	7	7	6

In terms of the weights, methods 3 and 4 place more emphasis on the serious crash indicator (0.35/0.34) than methods 1 and 2 (0.24/0.18). Methods 1 and 2 place more emphasis on the ride quality indicator even though it has been consistently ranked as one of the least important indicators. In general, Methods 1 and 2 appear to smooth the results.

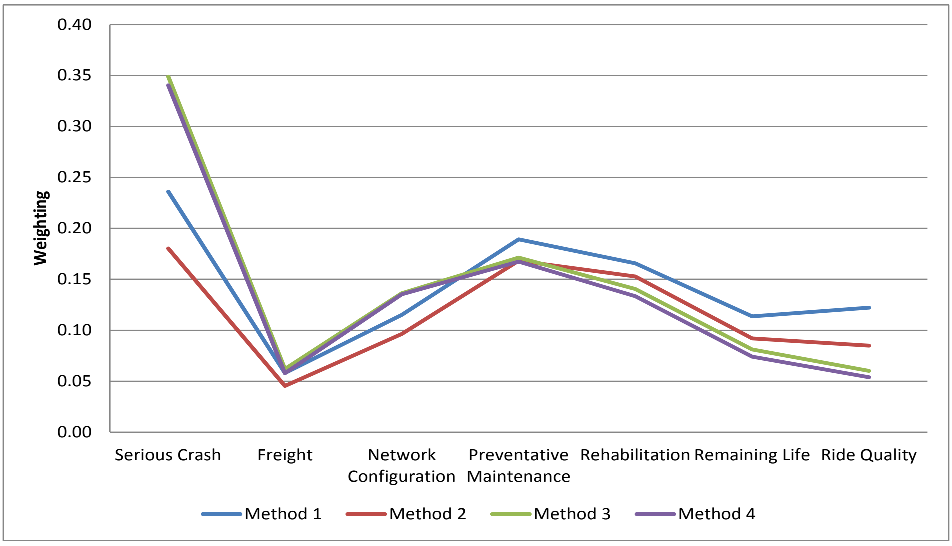


Figure 12 Comparison of aggregation Methods

Methods 3 and 4 are therefore considered to better represent the consensus of the group. Methods 3 and 4 show no significant difference between each other. Some literature (Yedla & Shrestha, 2007) suggest that geometric mean can magnify deviation in individual preferences and cause rank reversal of priorities but this phenomenon was not observed in this instance. Method 4 was therefore chosen as the final result which is supported by Saaty (1980) who advocated the method of geometric average of individual comparisons in determining group consensus.

The final weights (by indicator and by program) used in the calculation of the composite are as follows:

Table 12 Final weightings by indicator and by program.

Indicator	Indicator Weight	Program	Program Weight
Serious Crash	0.35	Safety	0.35
Network Configuration	0.14	Eff. Management	0.2
Freight	0.06		
Preventative Maintenance	0.17	Maintenance	0.45
Rehabilitation	0.14		
Remaining Life	0.08		
Ride Quality	0.06		

The AHP exercise has been useful in determining a preliminary set of weighting for the composite indicator. The plan now is to expand the survey to a wider number of asset management experts.

Appendix 2

The process to normalising existing indicators

Background

This appendix describes the normalisation processes used for the four indicators that are not reported as percentages in the Main Roads WA Annual Report. The approaches described below are a starting point and are intended to stimulate discussion regarding what one is trying to demonstrate by the single number and the sensitivity or insensitivity of the single number to potential impact factors.

The following indicators require normalisation for the purposes of generating a composite KPI:

1. Average Return on Construction Expenditure.

2. Average $ Cost of Network Management per Million Vehicle Kilometres Travelled.

3. Average $ Cost of Road Network Maintenance per Lane Kilometre of Road Network.

4. Black Spot Location Indicator.

The purpose of normalisation is to convert the KPI results to a score out of 10 so that the individual KPIs can be compiled into a composite. This allows results to be compared equitably with the performance of other regions and against the state value or baseline to determine trend patterns over time.

Approach

Normalising Average Return on Construction Expenditure

In order to normalise the expenditure weighted Benefit Cost Ratio (BCR) for a set of road projects within the State Development Program (Main Roads, 2012), the following methodology and formulae were used to calculate a score out of ten (KPI value):

RCE_SCORE = 10 (default) if the expenditure weighted BCR is greater than or equal to 2.

RCE_SCORE = 0 if the expenditure weighted BCR is less than 1.

RCE_SCORE = BCR x 5 where the expenditure weighted BCR is greater than or equal to 1 and less than 2.

Example:

If in South West Region (2012) the BCR for a set of State Development projects equated to 1.7 the following formulae would be used to calculate a RCE indicator score:

RCE_SCORE = BCR x 5 where the BCR is greater than or equal to 1 and less than 2.

RCE_SCORE = 1.7 x 5 = 8.5

Normalisation allows the result to be compared equitably with other regions that may have State Development projects and against the State value.

Normalising Average $ Cost of Network Management per Million Vehicle Kilometres Travelled

In order to normalise the financial efficiency of the Road Management System program (Main Roads, 2012), the following methodology and formulae were used to calculate a score out of ten

Take an average of the lowest five $ cost values across all regions (MGMT $ ave.) over the last five years (or years that we have consistent data for) and compare this value to the regional $ cost (REG $ cost) value of management within the Road Management System program in any given year.

Note: In this report consistent data was only available for the last three years.

MGMT_SCORE = 10 (default value) if the $ cost of management in the region (REG $ cost) is less than or equal to averaged state value over the last five years (three years in this report).

MGMT_SCORE = ratio (MGMT $ ave / REG $ cost) x 10 where the $ cost of management in the region (REG $ cost) is greater than the averaged state value over the last five years (three years in this report).

Example in the South West Region (2012):

MGMT $ ave = $886

REG $ cost = $2,180

Because the REG $ cost value is greater than the MGMT $ ave value the following formula was used:

MGMT_SCORE = ratio (MGMT $ ave / REG $ cost) x 10

MGMT_SCORE = ($886 / $2,180) x 10 = 4.07 (KPI value)

Normalising Average $ Cost of Road Network Maintenance per Lane Kilometre of Road Network

In order to normalise the financial efficiency of road and roadside maintenance works to maintain acceptable travel conditions on State roads (Main Roads, 2012), the following methodology and formulae were used to calculate a score out of ten (KPI value):
Take an average of the lowest five $ cost values across all regions (MAINT $ ave.) over the last five years (or years that we have consistent data for) and compare this value to the regional $ cost (REG $ cost) value of road and roadside maintenance works in any given year.

Note: In this report consistent data was only available for the last three years.

MAINT_SCORE = 10 (default value) if the $ cost of maintenance in the region (REG $ cost) is less than or equal to averaged state value over the last five years (three years in this report).

MAINT_SCORE = ratio (MAINT $ ave / REG $ cost) x 10 where the $ cost of maintenance in the region (REG $ cost) is greater than the averaged state value over the last five years (three years in this report).

Example in the South West Region (2012):

MAINT $ ave = $2,230

REG $ cost = $7,719

Because the REG $ cost value is greater than the MAINT $ ave value the following formula was used:

MAINT_SCORE = ratio (MAINT $ ave / REG $ cost) x 10

MAINT_SCORE = ($2,230/ $7,719) x 10 = 2.89 (KPI value)

Normalising Black Spot Location Indicator

In order to normalise the number of locations on the road network that meet State Black Spot criteria based on crash history (Main Roads, 2012), the following methodology and formulae were used to calculate a score out of ten (KPI value):

Take the highest number of qualifying locations across all regions (SBS) over the last five years (or years that we have consistent data for) and compare this value to the regional number (SBS REG #) of qualifying locations in any given year.

Note: In this report consistent data was available for the last five years.

SBS_SCORE = 0 (default value) if the number of qualifying locations within a region (SBS REG #) is greater than or equal to the highest state value over the last five years (five years in this report).

SBS_SCORE = 10 - (SBS / SBS REG #) x 10 where the number of qualifying locations within a region (SBS REG #) is less than the highest state value over the last five years (five years in this report).

As an example in the South West Region (2012):

SBS =19.53 (intersections)

SBS REG # = 14.81

Because the SBS REG # value is less than the SBS value the following formula was used:

SBS = 10 - (SBS / SBS REG #) x 10

SBS = 10 - (19.53 / 14.81) x 10 = 2.42 (KPI value)

Appendix 3

Comparison of the proposed new scalable indicators and the equivalent corporate indicator

Proposed new scalable indicator	**Existing corporate indicator**
Serious Crash (Effectiveness of Road Safety Strategies) Measures the extent to which the strategic goal of zero fatalities and serious accidents is met as well as quantifying the extent of the impact on the community as serious crashes (fatal + hospitalization) account for around 90% of the total crash cost. Data used in the calculation • Crash severity • Crash Cost • Vkt Crash Rates are calculated for 1km sections of road using three years of crash data (current year and two previous years) Crash Rate = crash count/ vkt Where: Crash count = number of fatal crashes + 0.05*hospitalization crashes Vkt = length * aadt AADT values are factored up to the current year using a linear growth rate of 2% per year until such a time that new growth rates are available. Hospitalization crashes are discounted to reflect the difference in the community's willingness to pay to prevent an accident (1 fatality = 20 hospitalization crashes based on 2010 willingness to pay figures). Crash rates are then converted to a score out of 10 for each 1km section using a linear equation: Score = -0.4*crash_rate + 10 Scores are then length weighted when the data	Black Spot location indicator D12#221226 One of the corporate indicators for State road network is the number of black spot qualifying locations identified on the network. Since the number of such locations is highly dependent on the amount of travel the indicator is expressed as an index determined by rate of the number of the black spot qualifying locations over the period of 5 years per average yearly travel expressed in terms of 100 MVKT. The calculated yearly indices based on "5-year moving averages" provide an indication of overall effectiveness of the black spot programs together with other road safety initiatives and road improvement programs over the time up to the current observation year for which the index is determined. The Black Spot Location Indicator (BSLI) is defined as the number of the Black Spot Qualifying Locations on the State Road Network, based on the current 5-year period crash data, per average yearly amount of travel across the entire road network in the state expressed in 100 MVKTs. The number of Black Spot qualifying locations is comprised of: a) Number of Black Spot Qualifying Intersections b) Number of Black Spot Qualifying Short Road Sections, <= 3 km c) Number of Black Spot Qualifying Road Lengths > 3 km (The Black Spot indicator needed to be normalised for use in this project. The process to

is aggregated to different levels (regional. Road, project etc.)	do this is described in Appendix 2)
<u>Availability to freight (availability of network to higher mass limit)</u> This provides a score that reflects the availability of the network to higher mass vehicles. This indicator is based upon the proportion of the network available in each of the Restricted Access Vehicle (RAV) networks. While similar in approach to the existing corporate indicator it extends the vehicles considered. The current approach only looks at networks that permit b double, double and triple road trains). Data used in the calculation • Road length available to different RAV classes • Maximum permissible mass for each RAV class Scoring is based on proportion of the main roads network available for each of the Restricted Access Vehicle (RAV) classes (Network 2 – Network 10). The scores are then combined into a single number by weighting each score based on the maximum permissible mass allowed to be transported by vehicles on each network class.	<u>Road Network Permitted for use by Heavy Freight Vehicles (D12#179893)</u> This indicator relates to the percentage of available state and national roads accessed by Class 10, Class 11 and Class 12 vehicles and in effect, the efficient movement of goods within Western Australia. An indicator is calculated for each of these 3 classes using the following equation: KPI(class)= Length(class) x 100/ Length(total) where: KPI(class) = Percentage of classified roads available to specified class of vehicles Length(total) = Total length of the Main Roads network in the state Length(class) = Length of the Main Roads network available to the specified class of vehicle (typically B-doubles) ANI Branch provides the total road length figures, HVO provides the information on road lengths available to various classes of vehicle by interrogation of the Vehicle Loading System (VLS) and networks built in IRIS.
<u>Network Configuration - Adherence to investigatory criteria</u> Measures the extent to which roads are planned and maintained to the optimum configuration parameters for seal width, carriageway width and geometry as defined by the Investigatory Criteria (IC). This indicator is related to the Corporate KPI ‘Network Configuration’ indicated in the right hand column and uses the same methodology to determine sections of road that do not meet the criteria . However the scoring methodology has	<u>Network Configuration – Roads (D12#179334)</u> Seal widths, carriageway widths and curve ratings of homogenous sections of the road network are compared against the investigatory criteria for the link subcategory that applies to that same section. The section of road is considered deficient if it fails any of the criteria. The Network Configuration KPI is the percentage of travel on roads that meet the criteria and is calculated as the complement (100% - value) of the percentage of travel on roads not meeting the investigatory criteria. This is described more

been tailored to meet the aims of this project – refer below. Data used in the calculation: • Carriageway Width • Horizontal Geometry • Vertical Geometry • Pavement and Seal replacement unit cost rates The calculation of the Network Configuration KPI is based on comparing the link category of each section of road against a series of investigatory criteria (IC) levels for seal width, carriageway width and curve rating. Individual scores are calculated for Seal, carriageway and curve which are then combined into a single indicator for Network configuration. For seal and carriageway, the score is based on the ratio comparing the actual width against the target optimum width. If a curve deficiency exists, the section of road is given a score of 0 otherwise the section scores 10 for curve rating. Individual scores are then value weighted using current unit rates when aggregated at a higher level (region, project etc.) where value = replacement cost as defined in the asset valuation process – add reference to methodology). Score = Actual (sealval + paveval + curveval) Target (sealval + paveval + curveval) Where Sealval = replacement cost of seal Paveval = replacement cost of pavement Cureval = replacement cost of pavement and seal This formula effectively gives the curve criteria a 50% weighting in the final score in recognition of the fact the curve rectification requires significantly more effort than sealing or widening a road. For the purposes of calculation, actual	fully in the left hand column.

value cannot exceed target value. In other words, if the road is built above the required standard, then target value is reset to actual value.	

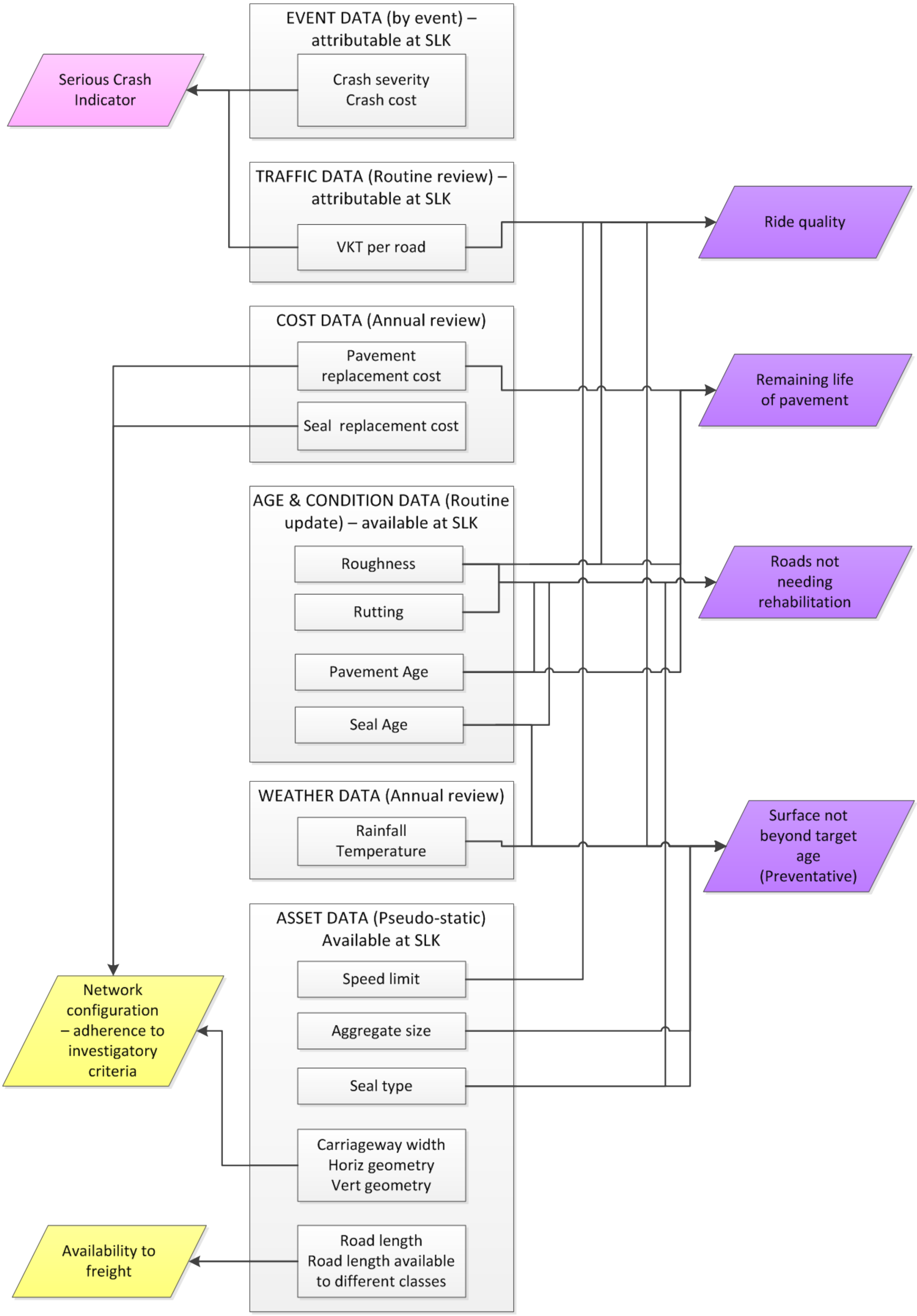
<u>Ride quality indicator</u>
 	
Measures how much actual road roughness deviates from an acceptable ride quality limit. It is calculated as a function of traffic volume and speed.
 	
The difference between this indicator and the Smooth Travel Exposure is the addition of the reference to the speed limit and traffic volume which changes the calculation process as shown below.
 	
Data used in the calculation
 	
• Roughness
• Speed limit
• Traffic volume
 	
Ride Quality is calculated as
 	
IRIgood = IRIgb * (110 / speed_limit) ^ 0.5
 	
Where IRIgb is the 'good' roughness limit for a road varied according to its traffic volume and represented by the equation:
 	
IRIgb = (7.1 * (ModAADT) –0.11)) + 0.05
 	
ModAADT is modified traffic volume giving heavy vehicles a weighting of 4 in order to compensate for the fact that the effect of roughness is significantly higher for heavy vehicles and is represented by the equation:
 	
ModAADT = AADT * (1 + 3 *% Heavy / 100).
 	
The IRIgood Value is compared against the actual IRI with KPI scores calculated based on deviation from the IRIgood value using the equation:
 	
Score = (((-100/6)/IRIgood)*IRI)+26.666667
 	
The linear equation is calculated such that IRI
	<u>Smooth Travel Exposure D12#179437</u>
	
	The Smooth Travel Exposure indicator shows the percentage of travel on the sealed road network that occurs on roads, which are within the roughness limits defined by the Asset Management Planning Investigatory Criteria.
	
	IRI roughness values for homogenous sections of the road network are compared against the roughness investigatory criteria for the link subcategory that applies to that same section. The section of road is considered deficient if the roughness exceeds the criteria. The roughness figure used for the comparison are the Lane Quarter car IRI values which are calculated as:
	
	iri_left = (iri_l_owp + iri_l_iwp) / 2;
	
	iri_right = (iri_r_iwp + iri_r_owp) / 2;
	
	The SAS code will compile the statistics for the KPI and will output an excel file for each year of calculation containing the percentage of travel and percentage of road length not meeting the investigatory criteria as well as composite statistics.
	
	The Smooth Travel Exposure KPI is the percentage of travel on roads that meet the criteria and is calculated as the complement (100% - value) of the percentage of travel on roads not meeting the investigatory criteria

less than IRIgood = 10 and IRI > IRIgood * 1.6 = 0 The scores are then length-weighted to derive the aggregated scores.	
<u>Surfacing not beyond target age – Preventative Maintenance</u> This indicator provides a measure of the extent that preventative (proactive) maintenance of road pavements is being adequately undertaken by comparing how far the actual age of the seal deviates from a target maximum seal age. Data used in the calculation • Seal Type • Seal Age • Rainfall • Temperature • Aggregate size • Traffic volume • To predict target seal age, Main Roads has adopted the methodology as described in Oliver, J 2009, Asphalt and Seal Life Prediction Models based on Bitumen Hardening, Austroads Project No: AT1064, ARRB Transport Research, Vermont South, Vic. Chip Seals (when seal type = 4,5,7,8,10) Where: tAve = (tMin + tMax)/2 tMin = yearly mean of the daily minimum air temperature (0C) tMax = yearly mean of the daily maximum air temperature (0C) Dura = the ARRB Durability Test result (days, taken as 10) AggSiz = nominal size of seal (nominal stone size, mm) Asphalt (when seal type is 1,2,3,12 or 11)	<u>Preventative Maintenance Indicator D12#179555</u> The Preventative Maintenance Indicator compares the seal age of the road against the target maximum surfacing age (optimum target age) for the section of road and reports on the percentage of the sealed network falling into the category of 'Good'. The data source for the calculation of preventative maintenance indicator is the Corporate Extract in SAS data set format. Actual seal age (SA) is compared against target age (TA) and one of four categories is assigned to each homogenous section of road: Good: SA < TA Mediocre: SA = TA - (1.3 * TA) Poor: SA = (1.3 * TA) - (1.6 * TA) Very Poor: SA > (1.6 * TA)

MRWA has adapted the Oliver Formula for asphalt to more closely model life expectancy (15 years for dense graded asphalt, and 10 for open graded). The equation for asphalt is: $SealLife = (0.16 \times tMin - 0.08 \times tAve - 0.848 \times \sqrt{AirVoids} + 5.217)2$ Air Voids are assumed to be 4% for dense graded asphalt, and 7% for open graded asphalt. Primer Seals (seal type = 6) are assumed to have a life of 2 years Slurry Seals (seal type = 9) are assumed to have a life of 7 years Actual Seal Age is compared with target seal age and a score out of 10 is assigned based on deviation from target age. Score is represented by the equation: Score = (((-100/6)/target)*s_age)+26.666667 The linear equation was calculated such that seal age less than target age = 10 and where linear seal age > target * 1.6 = 0 Scores are then weighted by replacement seal cost when aggregated in order to give more weight to more expensive assets that have been allowed to slip below threshold levels.	
<u>Roads not needing rehabilitation</u> Sections requiring rehabilitation are derived using an established model in which treatment triggers are calculated from observed road condition data. Data used in the calculation • Seal type • Seal Age • Pavement Age • Roughness • Rutting Relative costs per square metre for each level of triggered treatment are then used to score each	There is not currently an equivalent indicator in the corporate scorecard for this, although the methodology is used in pavement modelling.

section of road. Scores are then area weighted when aggregated to reflect the relative cost of rehabilitating pavements of different widths.	
<u>Remaining life of pavement</u> The remaining life for a road segment is defined as the estimated time until the first occurrence of one of the following: minimum road configuration measures are not met for that road segment; or the pavement's condition has reached a terminal state. Data used in the calculation • Roughness • Pavement Age • Pavement unit rates The minimum road configuration measures are the minimum Asset Management Planning road configuration measures. A pavement's condition is assumed to be terminal if the pavement roughness level reaches 110 NRM – in accordance with Main Roads' established Mean Age-Roughness Model. Details of the calculations used to calculate remaining life can be found in D06#10327 If remaining life is greater than 1, the road section receives a score of 10, If Remaining life is less than 1, the pavement is assumed to be past its design life and is given a score of 0.	There is not currently an equivalent indicator in the corporate scorecard for this.

Appendix 4: Relationship between input data and the proposed scalable indicators



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