Australasian Transport Research Forum 2010 Proceedings
29 September – 1 October 2010, Canberra, Australia
Publication website: http://www.patrec.org/atrf.aspx

New thinking for multi-modal corridors

Chris Vallyon[1] Anna Percy[2] Nik Vorster[3]

Email for correspondence: chris.vallyon@beca.com

Abstract

Most transport corridors in urban areas are multimodal in that they carry a mix of public transport, private transport and freight vehicles as well as being important walking and cycling links. Yet, most transport key performance indicators look only at the performance of a specific mode, for example vehicle volumes, car travel time surveys or public transport patronage in their reports whilst the performance of the corridor as such is not measured. A recent pilot study in Auckland, New Zealand, sought to develop a performance indicator that would include and combine modes of transport to allow an improved understanding of the operation of multi-modal arterial corridors.

This paper summarises the process and outcomes of work undertaken by the Auckland Regional Transport Authority and Beca to further improve on an existing Austroads performance indicator to create an improved and more flexible corridor performance indicator. The goal was to identify throughput and delay, which may differ by mode type, in a manner that would better inform decisions on how to manage the competing demands placed on arterial road space.

The result of this work led to the development of a new “Car Equivalent Utilisation” (CEU) indicator, which can assess the efficiency of a corridor more directly then previous Austroads indicators. It does this by looking at “person” speed and throughput of a corridor by mode type, and comparing it to a set benchmark for a lane of general traffic. The new indicator was based on the Austroads *Productivity: Speed and Flow* indicator. Like the original Austroads it uses a benchmark for both speed and volume, the primary difference being that vehicle occupancy is taken into consideration such that the “flow” is a measure of people, rather than private vehicles.

Using this new formula the pilot study found it possible to demonstrate the operation of the corridor by both public and private transport modes, and how changes to public and private transport influenced the results for each mode and the performance of the corridor as a whole.

The results of the pilot study were such that it was possible to analyse the available data and identify dwell times for public transport (boarding and alighting times) as the single biggest constraint on the overall efficiency of the studied corridor. Using a sensitivity test with the CEU indicator, it was possible to demonstrate how reducing public transport delay to match that of private vehicles would significantly improve the overall efficiency of the corridor.

The project did not attempt to study freight. The focus was primarily on road corridors; however the theory was extended to include possible comparisons with passenger rail.

The indicator and its development is provided to ATRF with the intention of promoting discussion as to its usefulness and potential for further development.

[1] Chris Vallyon, Beca Infrastructure, 132 Vincent Street, Auckland 1141, New Zealand
[2] Anna Percy, ARTA, 21 Pitt Street, Auckland 1141, New Zealand
[3] Nik Vorster, ARTA, 21 Pitt Street, Auckland 1141, New Zealand

1. Introduction

Urban growth inevitably places a strain on transportation corridors. This creates a challenge in how to use public space in a manner that balances the competing needs of various interests using this public space. On the one hand there is the challenge of sharing road space between different modes and on the other there is the challenge of balancing a road corridor's role of providing access to adjacent land with its role of moving people.

Most urban arterial transport corridors are multi-modal, in that road space is shared between public transport and private vehicles. Our roads and our public transport are both publicly funded, but questions remain as to whether we are able to obtain the most productive and efficient use out of the road network with this public funding. In order to answer this, it is necessary to have a performance indicator that takes into account the productivity of the individual modes of transport available to those engaged in travel. Determining each individual mode's productivity within a corridor allows decision makers to decide on the most efficient way to improve the productivity of the corridor. For example, where there is sufficient demand, public transport has the potential to improve the productivity of a corridor, but this is not currently clear from existing performance indicators.

Austroads has been in the process of developing and implementing a number of new performance indicators (also called performance metrics) designed to better understand traffic congestion. Although these provide improved understanding of the effects of congestion on private vehicles, it was felt by those on the study group that the contribution made by public transport to improve productivity is largely missed. For instance, a measure that records private vehicle throughput might not change at all even if public transport patronage doubled. Existing indicators tend to make no distinction between vehicles carrying 1 person or 50, despite the fact that a vehicle carrying 50 people is a considerably more efficient use of road space than 50 vehicles carrying one person each.

In an attempt to reconcile these issues, Beca and the Auckland Regional Transport Authority have undertaken a pilot study, taking an existing Austroads performance indicator and building upon it to provide a new indicator for comparing and assessing the speed and throughput of both public and private transport on a multimodal road corridor.

2. Properties of congestion

Congestion is essentially the term given to delay encountered by people wishing to travel from A to B . The most common form of congestion is in the form of a recurrent response to peak loading, i.e. it happens reliably every day as everyone tries to get to or from work at the same time. Demand exceeds available capacity, there is flow break down, and the journey takes longer than a trip of the same distance during off peak periods.

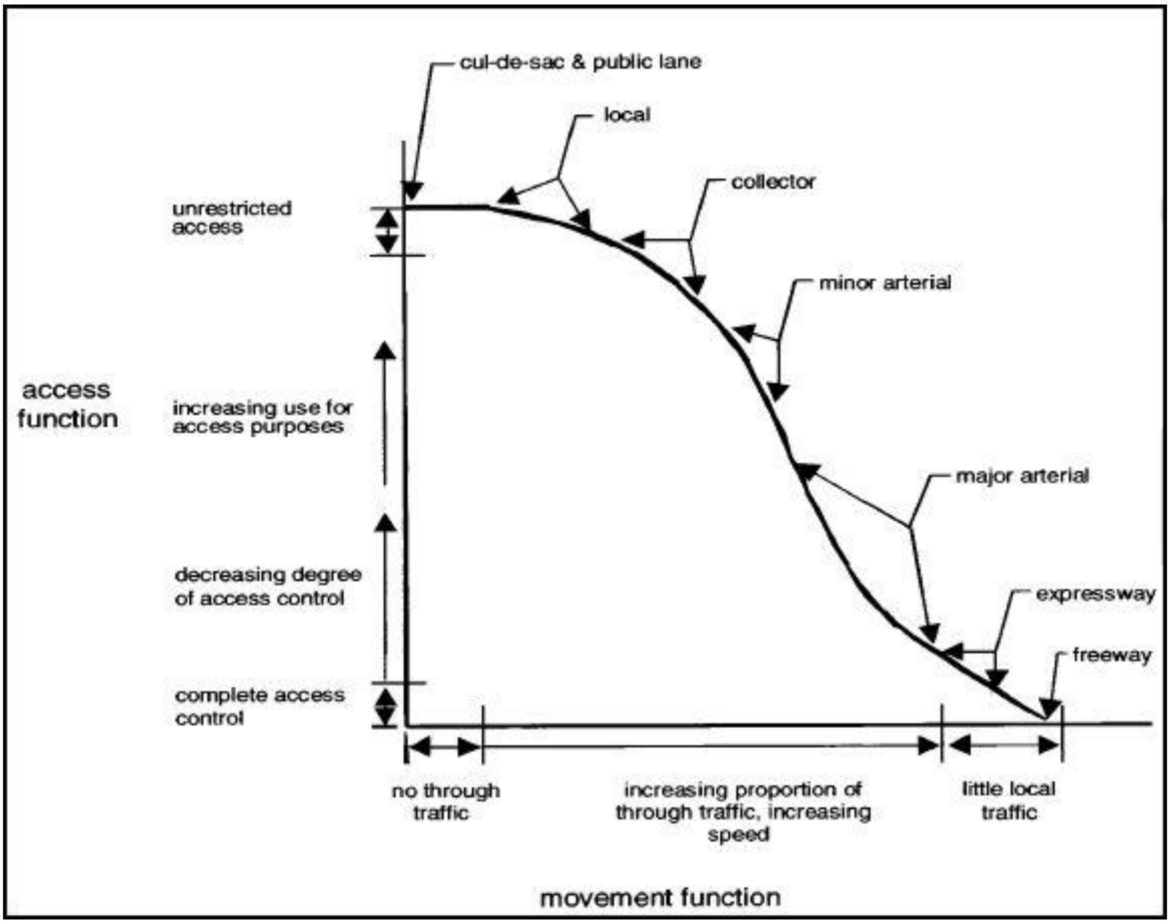
Congestion has three primary properties:

1) Spatial: where does the congestion occur, and how much of the network is affected
2) Temporal: When does the congestion occur, and how long does it last for?
3) Intensity: How significant is the delay? How many vehicles/people are affected?

For the purposes of planning investment it is particularly important to understand recurrent congestion, as knowledge of recurrent congestion provides an indication of where demand exceeds supply, and therefore provides a guide as to where to invest to improve capacity, manage demand, or improve existing operations to improve efficiency. Various efforts have been made to develop performance based indicators that assess some or all of the three properties of congestion.

However, performance indicators that simply identify where delay exists will not automatically inform decisions to improve the use of road space. Outside of a motorway / expressway environment, delays experienced for through traffic may be due to the corridor's role of providing access to the social and economic activities along the corridor. Source: **Transit New Zealand (2003).**, below, provides an illustration of road hierarchy, and how different road hierarchies provide a different mix of access and movement function.

Figure 1: Road Service / Function Relationships



Source: Transit New Zealand (2003).

Removing all delay for urban arterial corridors can only be achieved by removing the role of providing access along the route, essentially by turning all roads into grade separated motorways. This is neither attainable nor desirable as a city, in which every intersection has been grade-separated, without access to the activities that cause side friction on arterial roads, would not be a worthwhile place to live even if it were feasible to construct. For performance indicators to be useful in an arterial environment, they should allow for some level of delay due to the essential character of the road space.

3. Historic Austroads Congestion Indicators

In the early 1990s, Austroads developed three key congestion-related performance indicators. They are:

- Travel Speed / Time;
- Congestion Indicator (CGI); and
- Variability of travel time (VTT).

Travel speeds are obtained from floating vehicle surveys, where vehicles equipped with global positioning systems (GPS) travel set routes at specific times of the year. Start times and routes remain consistent between years, so that the results of each survey are directly comparable. The use of GPS provides accurate times at fixed locations and these times are used to derive travel speeds, which in turn are used to derive CGI (the difference between the observed speed and the speed limit) and VTT (variability of travel times).

Travel speeds can be compared with previous years to see whether conditions are getting better or worse; either along a specific corridor or averaged across a whole city. The results are currently used for such activities as to identify areas where congestion is getting worse and to demonstrate the post construction benefits of investment into the transport network.

However, there are two key limitations with these three formulae:

1) All three measures relate to the speed of private passenger cars using the road asset, and on their own do little to inform understanding of delays experienced by those using public transport. By focusing on passenger cars rather than 'people' they miss a key component of the 'intensity' of congestion by missing those using public transport (whose congestion experience may differ from those using passenger cars). Also, by missing the 'people' element of congestion, the indicators miss changes due to mode shift, public transport passenger growth, changes to vehicle occupancy, and other people based changes that might influence the efficiency of a corridor.

2) The VTT and CGI compare observed speeds with a target of un-obstructed free flowing traffic. This may be suitable for motorways, which should have no side friction and have no dual role (they exist solely to move traffic), however, the amount of delay experienced by road users outside of motorways can be heavily influenced by the corridor's urban role or place in the road hierarchy.

The three Austroads formulae provide some understanding the three properties of congestion, but only in relation to private vehicles.

4. Additional Austroads Congestion Indicators

4.1 Recent Austroads Developments

Recently, Austroads (2007) has developed a number of new performance indicators. These are:

- Traveller Efficiency (Travel Speed)
- Traveller Efficiency (Variation from Posted Speeds)
- Traveller Efficiency (Arterial Intersection Performance)
- Reliability (Travel speed)
- *Productivity (Speed and Flow)*

The new performance indicators have not yet replaced the historic indicators, but are a means of supplementing them, and can be used with either real time or floating vehicle data (Austroads, 2009). They offer a number of improvements for congestion monitoring. These include improving the ability to supplement GPS surveys with real time data sources (where available) and to increase the temporal coverage for congestion monitoring.

Another advantage of the new indicators is that they provide improved mechanisms for reporting on the performance of the network as a whole. The new reports aggregate the results into histograms, which show how much of the network is operating at specific levels of service. This improves upon the previous indicators in terms of illustrating the three properties of congestion – when, where, and how intensely congestion is affecting the performance of the network.

4.2 Productivity

Of specific interest to this study, was the new indicator for Productivity. Essentially, the speed and the flow are compared to the normalised speed and flow (a benchmark) to provide an indicator expressed as a percentage of Productivity, with the percentage result being an indicator of how well the corridor is meeting the 'benchmark' target.

This is described by Austroads (2007, p. 22) as follows:

> *The Productivity indicator is based on the product of speed and flow. A high productivity is achieved if both speed and flow are maintained near maximum values, i.e. near free-flow speed and capacity respectively. Low traffic flow and low speeds will correctly indicate a low productivity value. A low productivity, however, may be due to low traffic demand and does not necessarily indicate poor network performance.*
>
> *It is proposed to normalise the speed-flow product with reference or normalisation speed and flow values as follows:*
>
> $$\text{Productivity} = \frac{\text{speed x flow x 100}}{\text{speed}_{(nom)} \text{ x flow}_{(nom)}} \qquad \text{(for speed < normalisation speed)}$$
>
> *Or*
>
> $$\text{Productivity} = 100 \qquad \text{(for speed > normalisation speed)}$$

Parameters	***Freeway***	***Arterial Road***
Normalisation speed	*80km/h*	*35 km/h*
Normalisation flow	*2000 p.c/h/lane*	*900 p.c/h/lane*

Where p.c. = passenger cars

The new indicator can be used to improve understanding of data collected using existing data collection strategies and has been successfully trialled in Auckland. This means that it can be introduced without changing previous data collection strategies, and this consistency means that the historic data can still be used for identifying trends.

There are several advantages to the new indicator. The new Productivity measure essentially shifts the focus of the indicator from one that is based on road user experience, to one that is based on the overall efficiency of the corridor, and for this reason it is useful for road controlling authorities.

The comparison speeds have been reduced from the speed limit (used in CGI calculations) to a more realistic benchmark speed that allows for some measure of background delay along a surveyed corridor. Productivity is therefore more suitable for analysis outside of a grade separated motorway / expressway environment than previous indicators, as some background friction is expected where a corridor has access functions.

The Austroads Productivity formula combines flow/throughput (the number of customers served by the transportation asset) with speed (the customer level of service provided by the asset). Throughput / flow is a function of demand and capacity. The addition of speed shows how well the asset is performing. A corridor moving at 40km/h might be good for an arterial, but is a poor level of service for a motorway, and will result in driver frustration.

However, the new Productivity indicator does have some limitations. These are as follows:

1) The indicator is demand based. A low productivity outcome/measure need not mean poor performance, it might simply mean that the road has low demand or an excess of spare capacity (e.g. during the off peak, or on a rural road).

2) The indicator is still based on passenger cars. Although the Productivity indicator improves understanding of the intensity of congestion as compared with the earlier indicators, it still falls short of providing a measure of the actual number of *people* affected by congestion. For example, where a public transport investment is made in response to traffic congestion, the Productivity indicator would be unable to accurately capture the benefits of that investment.

Under the current Austroads indicators, a dozen buses each with one person on board and a dozen buses each with 51 people on board would have the same influence on the resulting indicator, although in reality they would be contributing a substantially different amount to the overall efficiency of the measured corridor.

5. Car Equivalent Utilisation Formula

5.1 Purpose

ARTA and Beca sought to use the strengths of the existing Austroads Productivity formula, but adapt it to allow a better understanding of the how the operation of a corridor affected “people” rather than just passenger cars, so that a comparison of modes could be achieved. The goal was to develop an indicator that could be applied to both public and private transport in assessing the operation of multimodal corridors including an understanding of how different modes contributed to that operation, both separately and when combined.

5.2 New methodology

The base Productivity formula remained relatively unchanged. The shift in thinking was to use ‘people’ rather than passenger vehicles. Note, the term ‘Car Equivalent Utilisation’ was given to distinguish it from the Austroads Productivity measure.

$$\text{Car Equivalent Utilisation} = \frac{\text{speed} \times \text{person flow} \times 100}{\text{speed}_{(nom)} \times \text{person flow}_{(nom)}}$$

(Expressed either per lane or per corridor)

Parameters	***Freeway***	***Arterial Road***
Normalisation speed	*80km/h*	*35 km/h*
Normalisation flow	*2000 veh x1.3*	*900 veh x1.3*
	***2600** people/h/lane*	***1170** people/h/lane*

The normalisation flow used to determine people throughput is based on average vehicle occupancy of 1.3 people. Although occupancy can vary by location and by time of day, 1.3 was chosen as a ‘benchmark’ suitable for average occupancy for commuter traffic in New Zealand.

One major decision involved the question of whether to identify a separate throughput benchmark for public transport that would differ from private passenger vehicles. The decision made was that if the modes were to be compared or combined, they should have the same benchmark, and for both modes the expression would be a Car Equivalent Utilisation (CEU) toward that shared benchmark.

Another point of difference to the original formula is that the result is not rounded down to 100%. The reason for this is that a bus lane operating at full capacity can have a substantially higher throughput than a vehicle lane operating at full capacity, simply because a higher density of people throughput is possible with public transport. In order to compare the two modes, neither mode would be rounded down to 100%.

In order to compare a bus lane and a car lane, the CEU of each lane can be determined separately. The total CEU of the corridor is also calculated so that the two modes can be compared directly and in terms of their contribution toward the total person-carrying capacity of the corridor.

As with the Austroads Productivity formula, the CEU combines flow/throughput (the number of customers served by the transportation asset) with speed (the customer level of service provided by the asset). By separating out public and private modes it is possible to see how the asset is performing in relation to different customer types, which is the key difference between the Austroads Productivity formula and the CEU formula.

5.3 Hypothetical Proof of Concept

Before collecting data, the study team undertook a desktop study using hypothetical values to establish a theoretical proof of concept.

The values for the hypothetical study are based on the study corridor, which has a car lane and a peak hour bus lane with a service frequency of 54 vehicles per peak hour.

Car Equivalent Utilisation = Speed * flow * 100 / (speed nom * flow nom)
Nominal speed: 35 km/h
Nominal throughput: 1170 people per hour, per lane
Lanes: 2

The total private vehicle throughput at 100% CEU would be 1170 people per lane at 35km/h.

$$CEU = \frac{35 * (900 * 1.3) * 100}{35 * (900 * 1.3)} = 100\%$$ (assuming a 1.3 vehicle occupancy)

The total potential CEU for public transport operating on the corridor is much higher than it is for vehicles. With 54 buses per hour and a maximum occupancy of 50 people, the hypothetical maximum is as follows:

$$CEU = \frac{35 * (54 * 50) * 100}{35 *(900 * 1.3)} = 231\%$$

People in public transport:	2700
People in private transport:	<u>1170</u>
Total people	3870

In both cases, the theoretical CEU assumes the target speed of 35km/h is met.

In terms of contribution to the total corridor, the following would be

$$CEU = \frac{35 * (3870) * 100}{35 * (900 * 1.3) *2 \text{ lanes}} = 165\%$$

Theoretically at least, it would be possible to exceed 100% CEU, not only for the bus lane but for the corridor as a whole if the bus lane is well utilised. Public transport has a higher theoretical throughput capacity through more efficient use of road space.

Note that this is not a true theoretical maximum throughput, as it was based on maximum patronage of the existing frequency of services for the corridor, rather than a maximum possible frequency of services.

However, it did provide a proof of concept, in that there were potential benefits of the CEU value over that of the Productivity value in terms of understanding the contribution of both public and private transport. Even with public transport improving people throughput to 3870 people per hour, the Austroads Productivity indicator would be showing a 100% Productivity, rather than recognising the added contribution of public transport.

This formula could theoretically also be used for rail.

Trams would be compared to an arterial road corridor equivalent, whereas commuter train services would have more in common with grade separation, and would be compared to an equivalent lane of motorway/expressway.

A rail corridor carrying 4,500 people during peak hour, with an average speed of 60km/h (including boarding and alighting times on route) could be compared against a motorway lane with a nominal throughput of 2,000 vehicles (or 2,600 people) at 80km/h.

$$CEU = \frac{65km/h * (4,500) * 100}{80km/h * (2,000 * 1.3)}$$

$$= 140\%$$

In theory, the greater potential throughput for rail would allow a Car Equivalent Utilisation greater than would be possible for a single lane of traffic. In the (hypothetical) example above, the rail corridor would be operating at 140% of the target for a grade separated car lane. As with the Austroads Productivity metric, this will be limited by demand. As with road based public transport, the theoretical throughput is higher, but the CEU would lesson if the public transport has a low average speed (i.e. lower level of service). CEU therefore can provide an assessment of how well rail is working as compared to road assets.

Direct comparisons can be made with equivalent road corridors if there are suitable origin-destinations that can be compared between road and rail, i.e. multimodal road-rail corridors.

6. Case study – data collection

6.1 Study Area

The study group now sought to test the theoretical values using real data for Dominion Rd, which is a busy multimodal arterial road corridor carrying a mix of private vehicles and buses. The corridor serves a dual function of providing movement between central Auckland and the southern suburbs as well as providing access for shop frontage which extends for most of the corridor. The conflict between these two roles has led to ongoing debate as to the use of road space for the corridor. Currently there is one lane of traffic in each direction, and a second lane that exists as on-street parking in the off peak and bus lanes during peak periods. The conflicting roles and the ongoing debate over the use of road space for this corridor are typical of many of Auckland's urban arterials.

Four sets of data were required for the CEU formula. These were as follows:

- Public vehicle travel speed;
- Private vehicle travel speeds;
- Public vehicle numbers and occupancy; and
- Private vehicle numbers and occupancy.

6.2 Average travel speeds

The Auckland region uses a public transport monitoring system called RAPID to collect and store public transport data. When a bus driver begins their route, they are supposed to enter the correct four digit route ID number into an onboard computer. As the bus traverses its route, the onboard computer interrogates a GPS and continually matches its location to the pre-programmed route. Each route has specific geocoded waypoints (usually bus stops) which are identified by the onboard computer. When the bus reaches a bus stop, the computer recognises this, and sends a time-stamp back to the data warehouse managed by the Auckland Regional Transport Authority. When the bus leaves, a second timestamp is sent, along with the number of tickets purchased and how many stages each ticket was for.

The project team began by identifying suitable bus stops along the route to use as 'screenlines' for comparing travel speeds and volumes. The average bus travel speed between these screenlines was obtained by identifying the services operating on the route and taking an average speed between the bus stops for the buses travelling within the study time period.

Private vehicle travel speeds were then obtained by using floating vehicle GPS surveys. This included the standard once per peak surveys, along with two days with multiple runs during the peak. The result was a representative sample of travel speeds, with the once per peak speeds being very similar to those obtained throughout the course of the peak. The GPS data was spliced to match the locations of the bus stops selected for public transport. This gave a direct comparison between public and private travel speeds.

6.3 Flow rates and occupancy

Cities with a "swipe-on swipe-off" system would likely have a very precise estimate of on board numbers. As Auckland has not yet introduced a swipe-on swipe-off system, bus occupancy is estimated by the RAPID system based on the number of tickets purchased.

Initial values for public transport throughput were found to be much lower than expected. One suggestion was the possibility that RAPID might be under reporting due to drivers failing to key in the correct route code at the start of the run. The number of services observed in RAPID was compared to the number of scheduled services and the shortfall was found to be between 40% and 50%, i.e., many of the services were being unreported in RAPID due to driver error. For each day of the study, the observed and scheduled services were compared and scaled up accordingly. The study group considered the implication of this and found this acceptable given that a 50-60% sample size was more representative than most studies.

SCATS volumes were used to obtain an estimate of vehicles travelling the corridor. SCATS is the intersection signal control system used in New Zealand. SCATS uses magnetic induction coils to identify vehicle lane occupancy and following distances at intersections. It is then able to infer volumes on each approach and dynamically update signal timings. The team used the volumes SCATS estimated at an intersection approach to be indicative of the throughput of the preceding block. The study corridor also had a count location at a midblock crossing, which provided a volume estimate for all through traffic at that point. It was considered that there may be a margin of error in the way SCATS calculates vehicle volumes, and as a result future studies could use a control count, however, SCATS was considered sufficient for a pilot study to establish a proof of concept.

Private vehicle occupancy was assumed to be 1.3 people per car. This was used as a theoretical value as the budget did not extend to a vehicle occupancy survey. It was considered that future surveys might include an occupancy count as well, if the pilot study found sufficient grounds for further use of the performance indicator.

Lastly, the vehicle count included freight vehicles, as it was not possible to identify freight volumes from the SCATS data. Freight volumes for the corridor were considered to be fairly low, however this will introduce a margin of error by over-estimating private vehicle volumes for the corridor. Again it was considered to be accurate enough to identify a proof of concept; however this issue should be taken into account for future studies.

6.4 Study timeframe

The pilot study looked at AM inbound peak and the outbound PM peak for the study corridor. The time periods studied were the first week of March and the first week of November 2009.

7. Case study – findings

The case study provided a number of interesting results. The key findings are as follows:

7.1 Findings for March 2009 (AM inbound)

	Public Transport	Private Vehicle
Person throughput by mode share:	1209	852 (655 vehicles)
% throughput by mode share:	59%	41%
Average Speed:	15km/h	35km/h
CEU:	44%	73%

Total peak hour people flow: **2050**

Total Corridor CEU: **59%**

7.2 Car Equivalent Utilisation Formula March 2009 (AM inbound)

Bus lane CEU: $\frac{15 * 1209 * 100}{35 * (900 * 1.3)}$

= 44%

Car lane CEU= $\frac{35 * (655 * 1.3) * 100}{35 *(900 * 1.3)}$

= 73%

Total corridor CEU (simplified): $\frac{44\% \text{ (bus lane)} + 73\% \text{ (car lane)}}{2 \text{ (total through lanes)}}$

= 59%

Total corridor CEU (expanded): $\frac{(15 * 1209 *100) + (35 * 655 * 1.3 *100)}{35 * (900 *1.3) * (2 \text{ lanes})}$

= 59%

7.3 Findings for November 2009 (AM inbound)

	Public Transport	Private Vehicle
Person throughput by mode share:	806	940 (720 vehicles)
% throughput by mode share:	46%	54%
Average Speed:	21km/h	33km/h
CEU:	40%	75%

Total peak hour people flow: **1740**

Total Corridor CEU: **58%**

7.4 Car Equivalent Utilisation Formula November 2009 (AM inbound)

Car lane CEU:

$$\frac{33 * (720 * 1.3) * 100}{35 *(900 * 1.3)}$$

$$= 75\%$$

Bus lane CEU:

$$\frac{21 * 800 * 100}{35 * (900 * 1.3)}$$

$$= 41\%$$

Total corridor CEU (simplified):

$$\frac{40\% \text{ (bus lane)} + 75\% \text{ (car lane)}}{2 \text{ (total through lanes)}}$$

$$= 58\%$$

Total corridor CEU (expanded):

$$\frac{(21 * 800 *100) + (33 * 720 * 1.3 *100)}{35 * (900 *1.3) * (2 \text{ lanes})}$$

$$= 58\%$$

The volumes carried by public transport are about a third higher in March than in November. There are two potential influences for this. The first is that the November surveys came during a period of uncertainty around service availability due to an ongoing public transport industrial dispute. This may be a reason for a decrease in public transport patronage and an increase in private vehicles between the two surveys. Unfortunately no data is available to see if there was also a rise in private car occupancy during this period. Another likely influence in the drop in public patronage is the fact that the November surveys come after tertiary institutions break for exams and the summer recess, and as a result there is a region wide seasonal drop in ticket sales.

Given that car speeds average around 33-35km/h, the delays experienced by buses are likely to be the result of delays due to dwell times (stopping, boarding and alighting, or waiting for a bus ahead that has stopped for boarding and alighting passengers). The dwell times are the only delay that public vehicles will experience differently from the relatively free flowing speeds for private vehicles on the same corridor.

A number of observations and conclusions can be inferred from the results of the pilot study. These are summarised as follows:

- The estimated proportion of people using public transport in March is substantially higher than November. Although there are lower average speeds for public transport (likely due to increasing delays associated with boarding and alighting times) the private car speed is actually slightly higher despite the corridor carrying an additional 310 people per peak hour;
- Between March and November there was a change in both the total number of people on the corridor, and mode split between public and private transport. Neither of these changes would have been detected using conventional Austroads indicators;
- A purely car-based assessment would have seen a rise in car volumes and a slight accompanying drop in car speeds for November, but would have missed the fact that there is also a decrease in the total number of people on the corridor. Average car

speeds were slightly higher in March, despite there being an additional 310 people per hour higher in the corridor.

- When public patronage in March is higher, there is a corresponding drop in average travel speeds (although there is little change to the overall CEU);

There are four factors contributing to the corridor's utilisation (people in vehicles, people in public transport, speed of private vehicles, and speed of public transport). Of these, the single most significant drain on the CEU of the corridor as a whole is the speed of public transport. The volumes of people using each mode are comparatively even, however, travel times experienced by public transport users are substantially slower than private vehicle users. Thus the asset is serving a similar number of customers using public and private transport; however those using public transport are experiencing slower average speeds.

Given that differences in travel times can be a key deterrent in the uptake for public transport, the findings are significant for public transport planning. However, they are also significant for the CEU of the corridor as a whole as almost half the 'customers' of the road corridor are those on public transport.

The pilot study provided a 'proof of concept' for the CEU indicator to inform debate as to whether or not bus lanes are an appropriate use of road space. For the pilot corridor, the evidence to maintain the bus lane is compelling for several reasons:

- The bus lane is used by about half the people (customers) using the corridor;
- Those using public transport encounter delays due to dwell times for boarding and alighting;
- The delays for public transport users is already a drain on the efficiency of the corridor, returning the bus lanes to general use would further aggravate this issue as it would further deteriorate the average speed (level of service) for public transport. This would further reduce the efficiency of the corridor (and likely result in people shifting back to private transport);
- It is also worth noting that the delays associated with bus dwell times identified above, would likely also influence travel times for vehicles travelling behind buses in a shared lane, thus there would be no benefit adding private vehicles (such as general traffic, T2, T3 or vehicles) to this lane, as they would not experience an increase in speeds, and would likely weave back into the general use lane when encountering delays.

A sensitivity test showed that if the public transport speeds were the same as those observed for private cars, the effect on public transport would be as follows:

- Public transport utilization with boarding and alighting delays: **44%**
- Public transport utilization without boarding and alighting delays: **104%**

Reducing March public transport delays to match those of private vehicles, would have the following effect on the CEU of the total corridor:

- Total corridor utilization (March 2009): **59%**
- Total corridor utilization with PT speeds matching private vehicles: **89%**

As a result of the sensitivity test, it is clear that investment in reducing delays for public transport to a similar level as cars would be worth further investigation for the purposes of improving the efficiency of the corridor. This provides useful quantitative data to support initiatives to reduce dwell times for public transport, e.g. through the swipe-on swipe-off ticketing system proposed for Auckland.

8. Rail corridors

Although the study did not specifically look at passenger rail, it is considered possible to use the throughput and speeds to assess a Car Equivalent Utilisation for a rail corridor, or multimodal road-rail corridor. As mentioned previously, grade separated passenger rail would be compared to grade separated vehicle benchmarks, whereas trams would be compared to arterial benchmarks in much the same way as a bus lane.

In some cases it might be difficult to directly correlate sections of road and railway. Unlike bus lanes, or tram lanes, which (usually) have a directly adjacent vehicle lane, commuter rail may vary from parallel road networks. This can be resolved through looking at links between the origin and destination for areas serviced by both road and rail. Train loading /patronage can be determined between two or more railway stations and this can be compared to a parallel road route.

Even without a direct road for comparison, the CEU value is still a useful means of comparing rail corridors as it provides a transferable benchmark indicator that combines both passenger loading and speed (level of service). For a well utilised rail corridor, this could provide a measure of how many equivalent lanes of (free flowing) motorway are provided by the rail corridor. By comparing speed between road and rail it is possible to compare rail and road assets to assess if delays faced by rail passengers may be influencing mode choice toward private vehicles. Although the throughput may be greater for rail due to the available capacity, a slow average speed may act as a deterrent to potential customers.

The indicator may also serve to demonstrate some of the benefit in investing in rail options, particularly if the result provides a higher peak time Car Equivalent Utilisation then a congested motorway.

9. Conclusions

The CEU formula proved to be very useful in providing a greater understanding of the operation of the corridor. It can be used to assess all three of the properties of congestion:

1) Spatial: by enabling a comparison of corridors. Where aggregated into a histograph this can also provide an understanding of how much of the network has poor utilisation;
2) Temporal: by comparing peak and off-peak, or seasonal variance. In theory, the formula could be used in combination with real-time data sources to provide near real-time utilisation;
3) Intensity: The CEU measure provides an improvement upon existing formula for understanding the intensity of congestion, as it directly provides an idea of the number of people actually experiencing a congestion incident, rather requiring this to be inferred from the number of vehicles.

The CEU indicator appears to be a useful means of providing an indicator capable of assessing the contribution of public transport to the operation of the corridor, and supplementing this gap in existing Austroads indicators. The results were specific enough that they demonstrated the primary shortfall of public transport for the chosen corridor, and it was simple enough to demonstrate how the efficiency of the corridor would improve if those shortfalls were addressed.

By combining throughput with speed it is possible to not only assess capacity issues but also customer level service. This could inform debate around the operation of a corridor, or funding for public transport, and could be used to assess where bus lanes are or are not required. Although not trialled here, with accurate car occupancy information it would also be possible to compare bus lanes with high-occupancy vehicle (HOV) lanes.

10. Unresolved Issues / Further Development

10.1 Demand

As with the original Austroads Productivity indicator, CEU is heavily influenced by demand. A low productivity result need not mean poor performance of the corridor. Those using either indicator will need to use their judgement to identify if a low value is a lack of demand. In both cases, a low throughput accompanied by a high speed is likely to be lack of demand, whereas a low throughput accompanied by a low speed is likely indicative of congestion caused by a lack of supply. The use of either indicator is therefore most useful where demand already exceeds supply. However, care should be taken where CEU or Productivity values are aggregated or compared across a network that includes areas of a lack of demand, as the lack of demand could be mistaken for lack of performance.

10.2 Walking and Cycling

The project team considered cycling as a desirable addition to the corridor utilisation, but did not reach a conclusion as to how best to do this. It was considered that one could count a cycle lane as half a ‘lane’ for the purposes of utilisation (based on a cycle lane being roughly half a vehicle lane width), but this would require almost 600 bicycles an hour for full utilisation. In New Zealand at least, this is a very unrealistic target. As an alternative, a benchmark target could be developed specifically for cyclists. This would need to be appropriate to the level of anticipated demand, as the CEU rate for cyclists would be influenced as much by demand as by the amenity of the corridor.

Where a cycle lane does not reduce the number of lanes available to vehicles (such as off street or shared walking/cycle paths), then cyclists could, in theory, simply be added to the throughput (and therefore total utilisation) for the corridor. This could only be compared to other corridors if known cycle counts are included in both totals, in order that the comparison is a fair one.

The team did not identify a means of including walking. Pedestrian trips tend to be shorter than vehicles and much less linear. Although delay is highly relevant to pedestrians, particularly where this can lead to unsafe interaction between vehicles and pedestrians, issues of amenity, safety, and accessibility tend to be more relevant than corridor speed and throughput.

10.3 On-street parking

The project team were of the opinion that where there is on-street parking there is sufficient space for another driven lane. The study corridor was taken to be two lanes wide, even at points where one lane is used for parking for some or all of the day.

There is the potential for a dissenting opinion that the formula should only be used for lanes that are actually available for carrying transport. However, on-street parking is publically owned land that has been made available for parking, and would otherwise be available to road users. The decision to retain it as parking is an important decision for the operation of the corridor, and just as important as the decision to remove it. The use of public land as parking should be weighed against the possibility that this space could carry up to 1170 people per peak hour as an alternative to parking and the benefits of either should be weighed. To do this, the lane can and should be included in the total potential capacity for a corridor. While the issue of parking can be highly political, there is an over-riding need to inform such decisions based on good data.

10.4 Freight

The study did not seek to provide a metric for assessing the level of service as applied to freight. However, in the course of developing the indicator the speed and volume of general traffic lanes must be determined. If the volumes of freight are also known, then conclusions can be drawn on how low speeds for general traffic lanes could be adversely affecting freight movements.

10.5 Vehicle Occupancy

While considering the effects of an assumed private vehicle occupancy, it was also noted that, with good occupancy data, the methodology might be useful for assign the benefits of T2 and T3 lanes, or of comparisons between bus lanes and HOV lanes, however, this fell outside the scope of the pilot study.

References

Austroads 2007, *National Performance Indicators for Network Operations*, Report AP-R305/07, Austroads, Sydney.

Austroads 2009, *Implementation of National Network Performance Indicators: First Round Results*, Austroads, Syndey

Transit New Zealand 2003, *State Highway Geometric Design Guide Part 2*, Transit New Zealand, Wellington.