A REVIEW OF TRAFFIC GROWTH RATE CALCULATIONS

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ABSTRACT

A review of the long term traffic data collected over a period of 30 years from the Perth metropolitan urban arterial routes has found that in most cases the long term traffic growth does not follow the compound traffic growth rate model proposed by the pavement design procedures. It was also observed that on many of the roads, the increase in traffic volumes follows a linear path where the annual increase in traffic changes by a constant number of vehicles per year, irrespective of the length of time following the opening of the road or the current traffic levels.

The traditional compound traffic growth rate approach to determine the design traffic growth rate and then the cumulative growth factor for pavement thickness design can significantly over estimate the design traffic if the compound growth rate is not carefully selected and adjusted for the design life of the pavement. This over estimation of design traffic may lead the pavement designer to select a pavement type with a high capital cost and overdesign the pavement thickness resulting in the unnecessary use of materials, resources and finances. Austroads *Pavement Design Guide, Part 2: Pavement Structural Design*, only provides a traffic design procedure for the calculation of design traffic based on compounding traffic growth.

This paper presents a review of the traffic data collected from three Perth metropolitan arterial roads and compares the results of the traditional compound traffic growth rate model to an alternative linear traffic growth rate model. The findings of this review highlight the importance of having sound long term traffic data available to pavement designers to ensure the most appropriate traffic growth rates model are considered when determining the pavement design traffic. With a sound design traffic analysis, the pavement designer can select the most sustainable new pavements or pavement rehabilitation treatments.

The views expressed are those of the author and not necessarily those of Main Roads Western Australia.

INTRODUCTION

A study completed in 2011 by Main Roads Western Australia Pavements Engineer Dr Xiaoyan Mao (Mao 2011), assessed the Average Annual Daily Traffic (AADT) volumes for 10 major roads in the Perth Metropolitan Area. The traffic data was gathered by searching the archives and historical data bases of short term traffic counts and processing the information into charts of AADT and Time for each segment of each road in the study. This study brought together traffic volume data from over 40 years of records that had been stored in several systems within Main Roads Western Australia. The traffic data itself is very interesting in how it describes the development of Perth as a City and provides a long term view of the actual traffic growth of Perth.

Where only Annual Average Weekday Traffic (AAWT) was available the analysis calculated an AADT value by determining the AAWT to AADT ratio from selected short term seven day traffic counts and multiplying the ratio to the AAWT traffic value. In most cases the AAWT to AADT ratio was equal to 0.9. Where only two way traffic data was available the analysis also divided the total AADT traffic by 2 to calculate the single carriageway traffic.

The analysis of this long term traffic data showed that the traditional compound traffic growth analysis did not provide the best fit for the long term traffic data and that in many cases traffic growth could be better represented linearly. This linear increase in traffic volume shows that a growth rate in the traffic can be described as a constant that is independent of the current number of vehicles and the length of time the road has been open to traffic.

This paper presents some of this long term traffic data and proposes an alternative method to analyse traffic growth that is based on a constant increase in the number of vehicles per year.

Where practical the notation used in Guide to Pavement Technology, Part 2: Pavement Structural Design, AUSTROADS, 2010 has been used.

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BACKGROUND

Linear growth rate

Linear growth is the same as a constant growth rate where the growth of a population is constant and independent of the existing population. An example of a constant growth could be filling up a tank with water from a tap where the flow rate from the tap can remain at a constant and independent for the volume of water in the tank.

The total population at any time can be expressed using the following equation;

$$N_t = N_0 + k.t \quad (1)$$

where

N_t = population size at time t

N_0 = initial population size

k = growth rate constant, per time interval

t = number of time intervals.

The linear growth rate constant for a set of short term traffic counts can be determined by applying a linear regression of the results and calculating the gradient of the line.

For the purpose of pavement design a cumulative growth factor needs to be calculated to determine the total number of vehicles that are be carried by the pavement over the pavement design life (P). This cumulative growth factor can be determined using the sum of a finite arithmetic series formulae and dividing it by the initial traffic using the following equations.

$$CGF = \frac{P \times \frac{(N_0 + N_p)}{2}}{N_0} \quad (2)$$

$$N_p = N_0 + (P \times LGR) \quad (3)$$

where

CGF = Cumulative Growth Factor for design life P years

P = pavement design life in years

N_0 = initial AADT

N_p = final AADT at P years

LGR = Linear Growth Rate, the average annual increase in AADT over the pavement design life.

Compound growth rate

Compound growth and exponential growth are when the growth rate of a population can be expressed as ratio of the current size of the population, and the population growth can be considered as unconstrained. Compound growth is a commonly used by the financial industry to describe the growth of funds where the time period is years and growth is typically unconstrained.

The natural growth of an unconstrained population typically follows a compound or exponential path where a population can increase in size and is dependent on the initial population until the population becomes constrained by some external factor such as environmental influences, available resources or physical space constraints. A typical example of a natural exponential growth is the growth of bacteria where the bacteria can double in number every 30 minutes if provided enough food and a warm temperature. The exponential growth of a population can be expressed using the following equation;

$$N_f = N_0 \times (1 + R_c)^t \tag{4}$$

where

N_f = final population size

N_0 = initial population size

R_c = growth rate per time interval (ratio)

t = number of time intervals.

The exponential growth rate is calculated by applying an exponential regression on a set of population values using natural logarithm equation y = k.e^x where the compound growth rate $R_c = e^x$-1.

For the purpose of pavement design a cumulative growth factor needs to be calculated to determine the total number of vehicles that will be carried by the pavement over the design life. The traffic growth rate factor CGF can be calculated for design period P using the equations below.

$$CGF = \frac{(1 + R_c)^P - 1}{R_c} \; for \; R_c > 0 \tag{5}$$

where

CGF = Cumulative Growth Factor for design life P years

P = pavement design life in years

R_c = annual compound growth rate in AADT over the pavement design life (ratio).

The cumulative growth factor can be calculated for two compound growth rates if necessary to represent changes in growth rates for different period during the design life. Formulae for these calculations are described in Guide to Pavement Technology, Part 2: Pavement Structural Design, AUSTROADS, 2010, Appendix C and summarised below.

$$CGF = \frac{(1+R_1)^Q - 1}{R_1} + (1+R_1)^{Q-1} \times (1+R_2) \times \left\{\frac{(1+R_2)^{P-Q} - 1}{R_2}\right\} \qquad R_1, R_2 > 0$$

where

CGF = Cumulative Growth Factor for design life for Q year plus P years

P = Pavement design life in years

R_1 = annual compound growth rate in AADT for the first Q years (ratio)

R_2 = annual compound growth rate in AADT for the remainder P years (ratio).

Brief History of the Population of Perth, Western Australia

Perth following colonial settlement

Perth was settled as a British colony in 1829. The growth in its population since settlement has been shown below in Figure 1 and Figure 2. In broad terms the population growth of Perth can be described as three separate phases of growth with a relatively small rate of increase in the total population size between settlement in 1829 to the 1890's. It appears the gold rush in the 1890's commenced a sustained annual increase in population until the 1950's averaging about 5,000 people per year. Following the Second World War a new sustained population increase influenced by post war migration commenced and appears to have remained generally constant until about 2006 consisting of 22,500 people per year. This senses population data also suggest that there has been a new upswing in the rate of population growth since 2006 which is thought to be associated with the current mining boom in the north west of the state. It is unknown if this increase in population growth will be sustained over the longer term or it may return to the previous levels.

Perth's population between 1954 and 2010 has been both assessed by applying an exponential and linear regression and these lines have been projected forward by 20 years on Figure 1 and Figure 2. This period of population growth can be considered as relevant to the traffic analyses presented in this paper because it covers a similar time period. It is proposed in this paper that the linear increase in population is directly related to the observed linear increases in the observed traffic growth.

The exponential regression analysis of population growth from 1954 to 2010 shows that the population has been growing at a rate of 2.5%. The linear regression analysis for the same period shows that the population has been increase at relatively steady rate 22,450 people per year. Both methods of regressing the population have a very good and very similar R^2 value indicating that, at least mathematically, both methods are equally valid. The linear regression constant of 22,450 can be represented as a rate of increase of 5.7% of the population in 1954 down to an increase of 1.3% of the population in 2010 that incrementally reduces as time progresses. The significant difference between the two methods of analysing the population growth is that in 20 years' time the exponential analysis shows the population of Perth as 2.8 million and the linear analysis shows Perth as 2.0 million people. The recent upswing in the Perth population commencing in 2006 may or may not be sustained into the future. This difference in the approach to the analysis highlights the difficulties for any government to plan for the future.

In 1954 Perth's population was only 395,000 and population growth had little geographical constraints. In 2010 Perth's population is now 1,700,000, over four times larger and to cater for the increasing population the physical size of Perth has also increased. Perth's urban sprawl has continued extending outwards without any real natural boundaries. The residential suburbs of Perth currently extend about 80 kms from Yanchep to Rockingham and about 30 kms from the Indian Ocean coast line to Mundaring requiring the periodic extension and development of new roads to allow for the increasing population and hence traffic. These physical constraints and factors like travel time and pollution are expected to create the constraints that gradually resist the unconstrained nature of population growth.

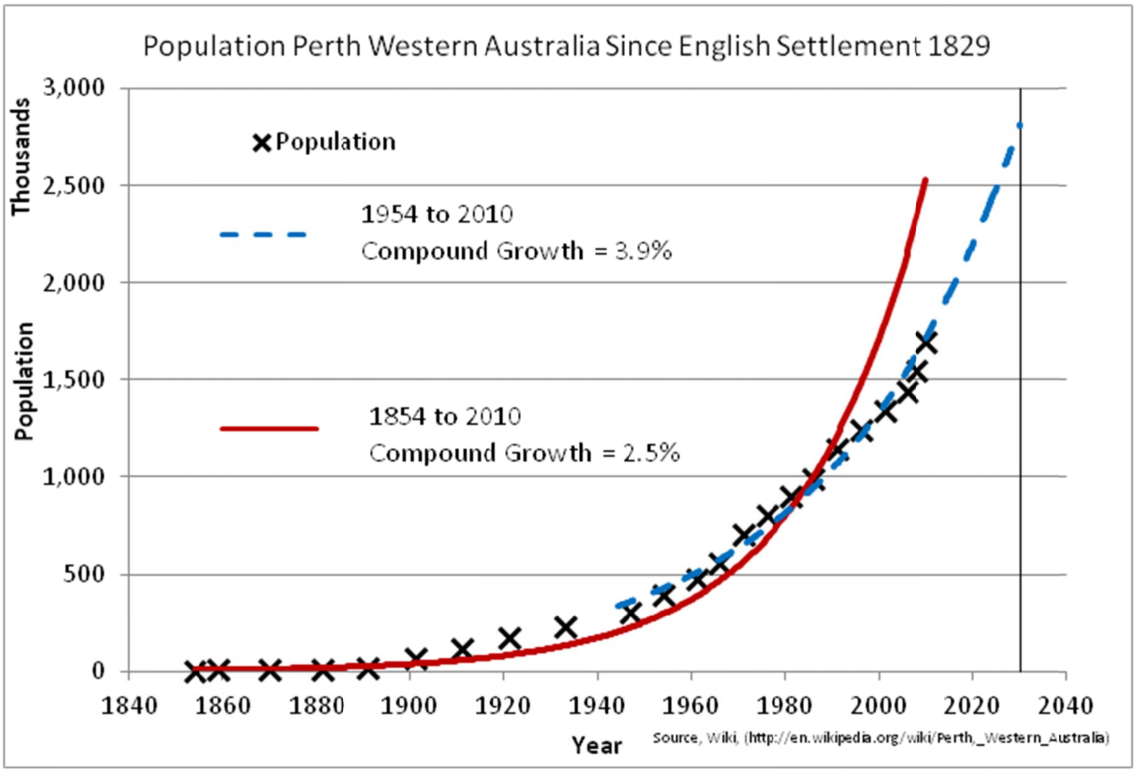

Figure 1: Population of Perth since English settlement

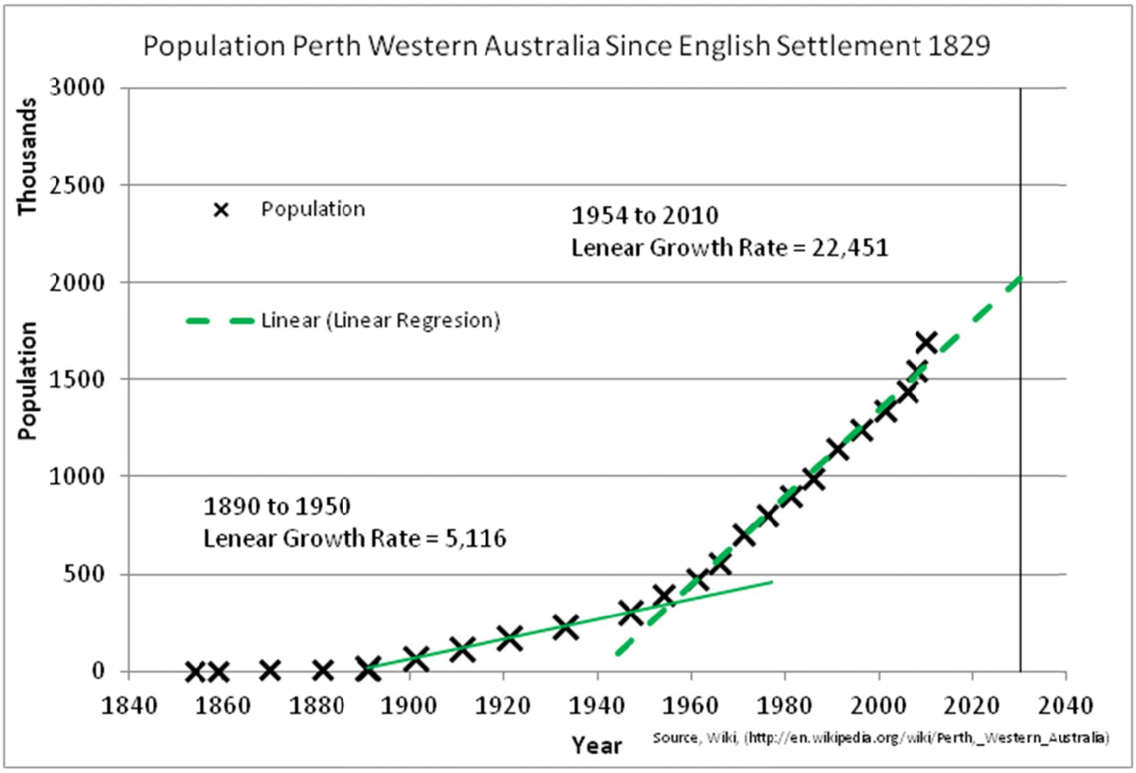

Figure 2: Population of Perth since English settlement

Current approach to traffic growth analysis

Most pavement design guides require the pavement designer to determine one or two applicable compound traffic growth rates for the design period of the road. These compound growth rate are then used to determine a cumulative growth factor (CGF) for the design period.

The selection of the appropriate compound growth rates can be one of the most problematic steps in the determination of the design traffic. A growth rate that is too high is likely to generate a very conservative design traffic especially for pavements with a 40 or more year design life and a growth rate that is too low may generate a design traffic that is too small.

It has been observed that for most new roads there is a steady increase in traffic for at least the first 10 years of the life of pavement and compound growth rates are typically between 5% and 10%, the growth rate then gradually reduces towards 1% to 3% over the next 30 years.

Without traffic survey data the designer is required to estimate the current traffic value at the start of the project then project this forward to the opening date and then determine the growth rates for the pavement life using any information that is available that may include;

- traffic growth rates from older road serving a similar function
- traffic modelling undertaken from land use planning and inter-regional transport modelling
- the effect of any new proposed road links in the future
- adopting a regional traffic growth value.

TRAFFIC VOLUMES FROM THREE SELECTED PERTH ROADS

The following charts present selected results from the study by Mao (2011), and each set of results have been assessed to determine the compound traffic growth rate (R_c – solid red line with the regression equation and R^2 value above the line) and the Linear Growth Rate (LGR – dashed green line with the regression equation and R^2 value below the line).

This paper has focused on selecting traffic data for roads where over 30 years of traffic records were available and where additional road links have not directly reduced the traffic volumes by creating additional routes.

A problem with the linear growth rate model is that it can only be expressed as the change in the total traffic volume at a particular time. It can be expressed as a percentage of the total traffic for a particular year but the percentage will change depending on what year is selected. The linear growth rate is not transferable between different roads. An advantage of the linear growth model is that it is independent of the initial traffic estimate at the time of opening unlike the compound growth model, which generates a different growth rate depending on what is chosen as the initial year.

To illustrate the differences between the two methods of traffic growth analysis a trial design traffic has been calculated using the following assumed heavy vehicle traffic values. These heavy vehicle traffic values have been estimated and do not reflect the actual measured heavy vehicle traffic results and have been included to illustrate the difference in the alternative traffic growth analysis.

$$DESA = 365 \; x \; AADT \; x \; DF \; x \; \%HV/100 \; x \; LDF \; x \; CGF \; x \; N_{HVAG} \; x \; ESA/HVAG$$

where

$DESA$	=	Design Equivalent Standard Axles
$AADT$	=	Projected Annual Average Daily Traffic 2012
DF	=	1 , Direction Factor
$\%HV$	=	5%, Average percentage of heavy vehicles
LDF	=	1.0, Lane distribution Factor for single and two lane roads
LDF	=	0.7, Lane distribution Factor for three or more lane roads
CGF	=	Cumulative Growth Factor
N_{HVAG}	=	2.7, Average number of axle groups per heavy vehicle
$ESA/HVAG$	=	1, average number of Equivalent Standard Axles per Heavy Vehicle Axle Group.

The traffic data and design traffic values presented in this paper are illustrative examples and must not be used for the purpose of pavement design without the express consent of Main Roads Western Australia. The traffic data presented has been selected for the purpose of comparing traffic growth modelling procedures and any pavement design must include an assessment of other classified traffic data.

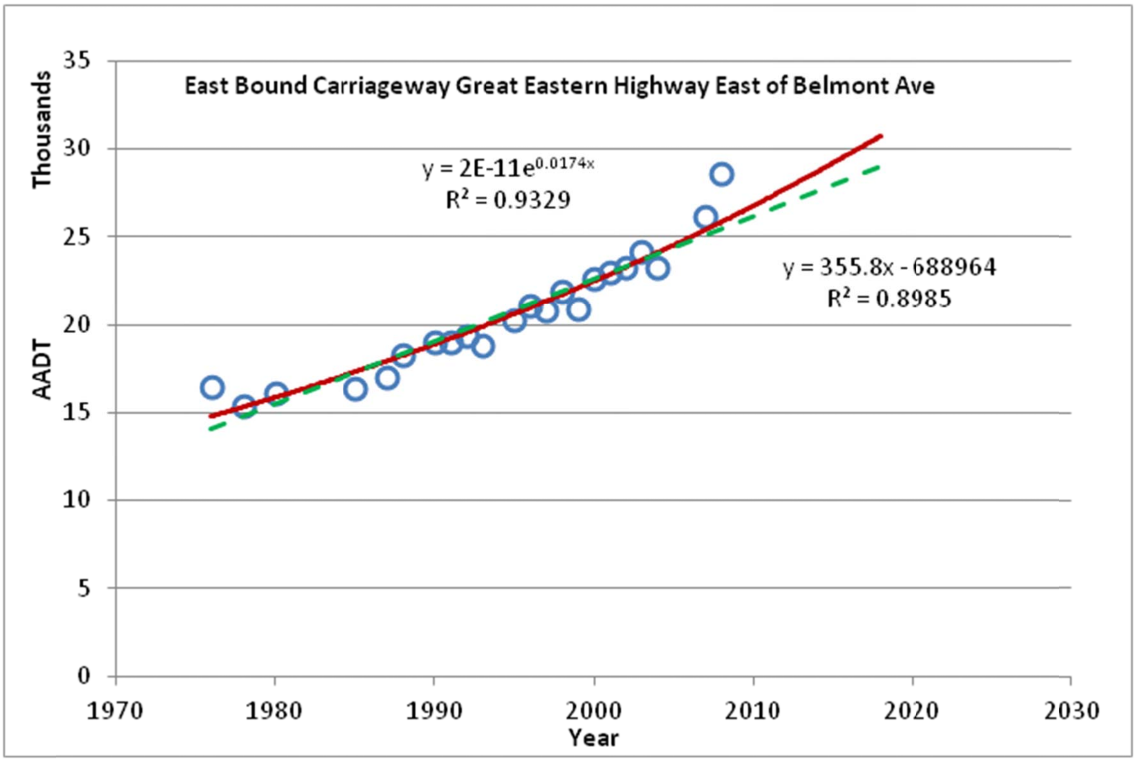

Figure 3: East bound, Great Eastern Highway @ Belmont Ave, inner city location

This segment of road is currently a four lane urban highway that has been a major district distributer road for Perth throughout its development as a city. This location is relatively close to the centre of the CBD and the traffic growth rate is small. It carries a mixture of commuter traffic and some local freight. The graph shows that either of the regression approaches is applicable to the data with the compound growth rate regression having the better R^2 value.

The exponential regression shows that the traffic is increasing with a rate R_c = 1.8%, and a linear growth rate = 356 vehicles per year. This relatively low traffic growth rate sees only a relatively small difference in the predicted traffic in 20 year's time. Both methods of determining the CGF value provide a similar result.

The design lane traffic using the two growth rate methods.

	Compound	**Linear AADT/year**
Growth rate	1.8%	356
20 year DESA's	3.6×10^7	3.3×10^7
40 year DESA's	8.6×10^7	7.3×10^7

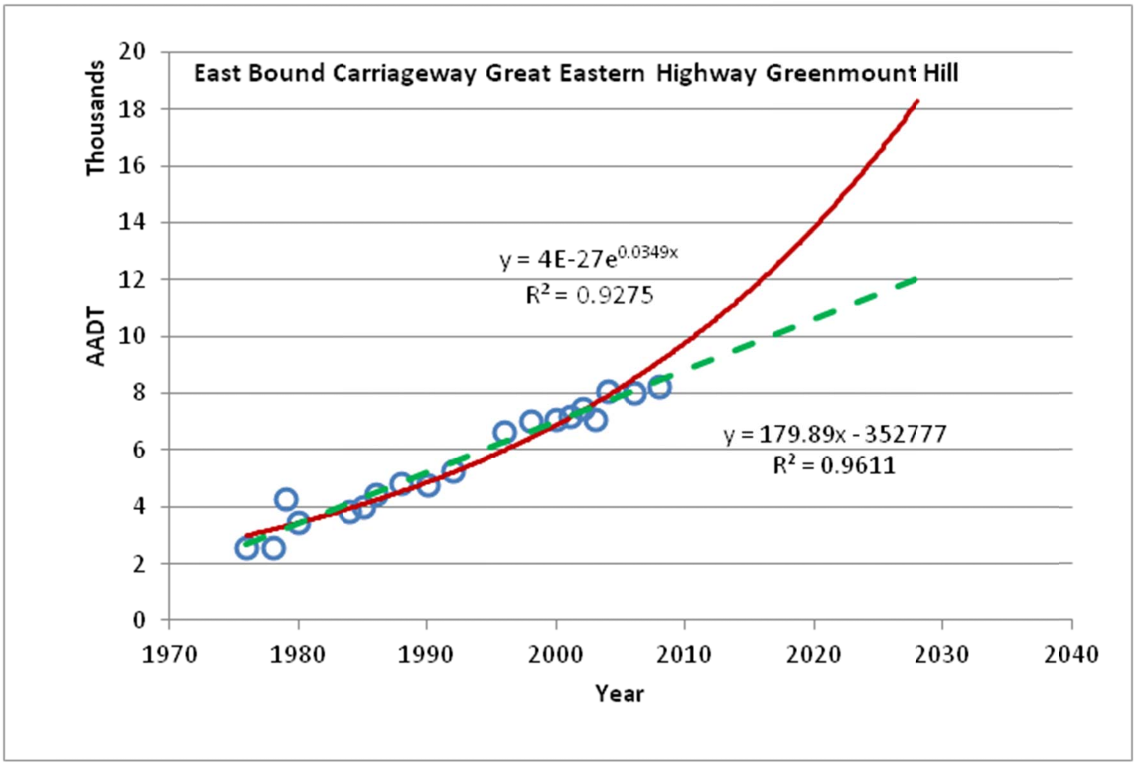

Figure 4: East bound Great Eastern Hwy, Green Mount Hill, outer metropolitan location

This segment of Great Eastern Highway is currently a four lane outer metropolitan highway and a major district distributer that is also a National Highway. It carries commuters and a substantial amount of freight and agricultural produce. The graph shows that a linear regression of the traffic data provides a better fit compared to the exponential regression. The compound growth rate is double the growth rate of the same highway at Belmont avenue near the CBD and the divergence between the two methods of traffic growth analysis is now more pronounced.

The exponential regression shows that the traffic is increasing at a rate R_c = 3.6%, and a linear growth rate = 180 vehicles per year. This compound traffic growth rate shows that there is a significant difference in the predicted traffic in 20 years time of about 6,000 vehicles per day. If the design period of the pavement is 40 years the compound traffic estimate is almost double the linear traffic estimate.

The design lane traffic using the two growth rate methods.

	Compound	**Linear AADT/year**
Growth rate	3.6%	180
20 year DESA's	1.3×10^7	1.1×10^7
40 year DESA's	4.0×10^7	2.5×10^7

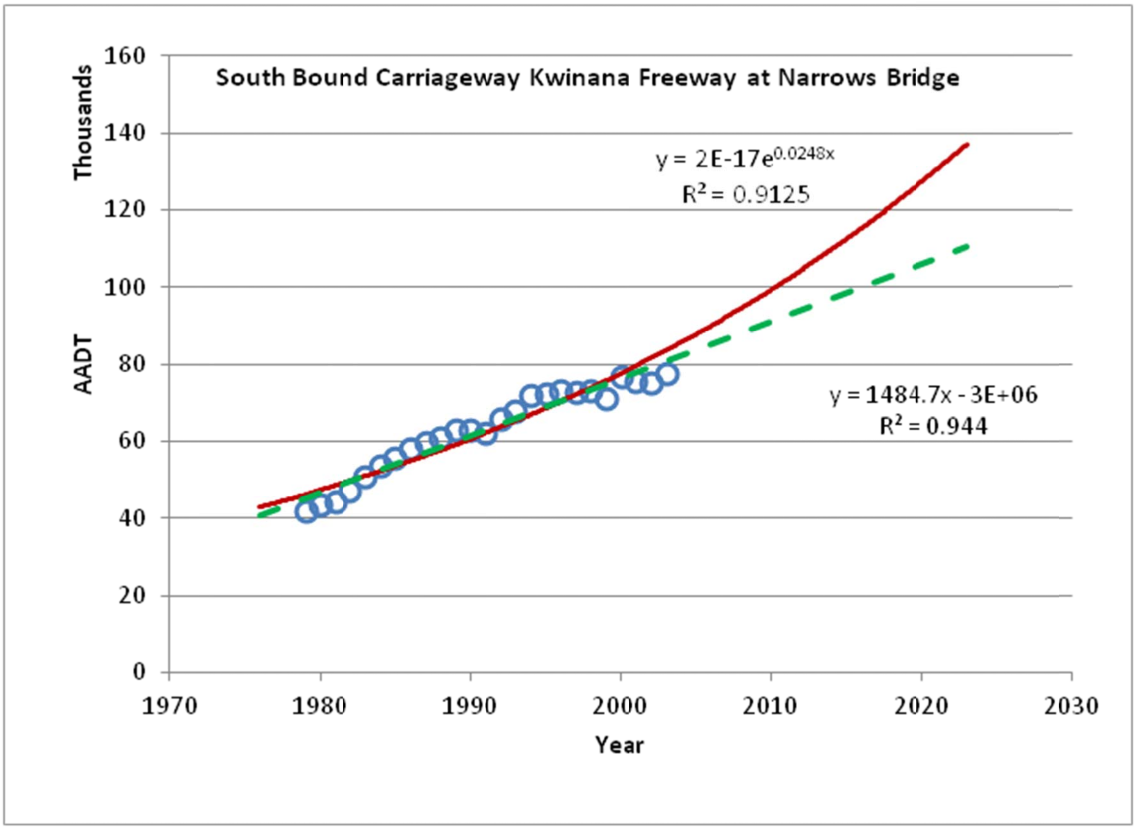

Figure 5: South bound Kwinana Freeway, Narrows Bridge, inner metropolitan location

This segment of road is a very important district distributer and is currently five traffic lanes wide in the south bound direction. Prior to the duplication of the Narrows bridge in 2001 there were three south bound traffic lanes. The road forms the primary link connecting the north and south sides of the Perth metropolitan area over the Swan River. The traffic data shown on the graph reflects some of the extensions to the Kwinana Freeway over the survey period where there is a bump in the line. Following each extension to the freeway the traffic experiences a upswing in volume that trends more closely to compound growth for about 5 to 10 years, however over the long term data trends around the linear regression slightly better than the exponential regression.

The exponential regression shows that the traffic is increasing at a rate Rc = 2.5%, and a linear growth rate = 1,485 vehicles per year. There is a significant difference between the two methods in the predicted traffic in 20 years time of about 30 000 vehicles per day which would create the need for an extra traffic lane. If the design period of the pavement is 40 years the compound pavement design traffic estimate becomes about 35% greater than the linear traffic estimate.

The design lane traffic using the two growth rate methods.

	Compound	**Linear AADT/year**
Growth rate	2.5%	1485
20 year DESA's	8.6×10^7	7.3×10^7
40 year DESA's	2.3×10^8	1.7×10^8

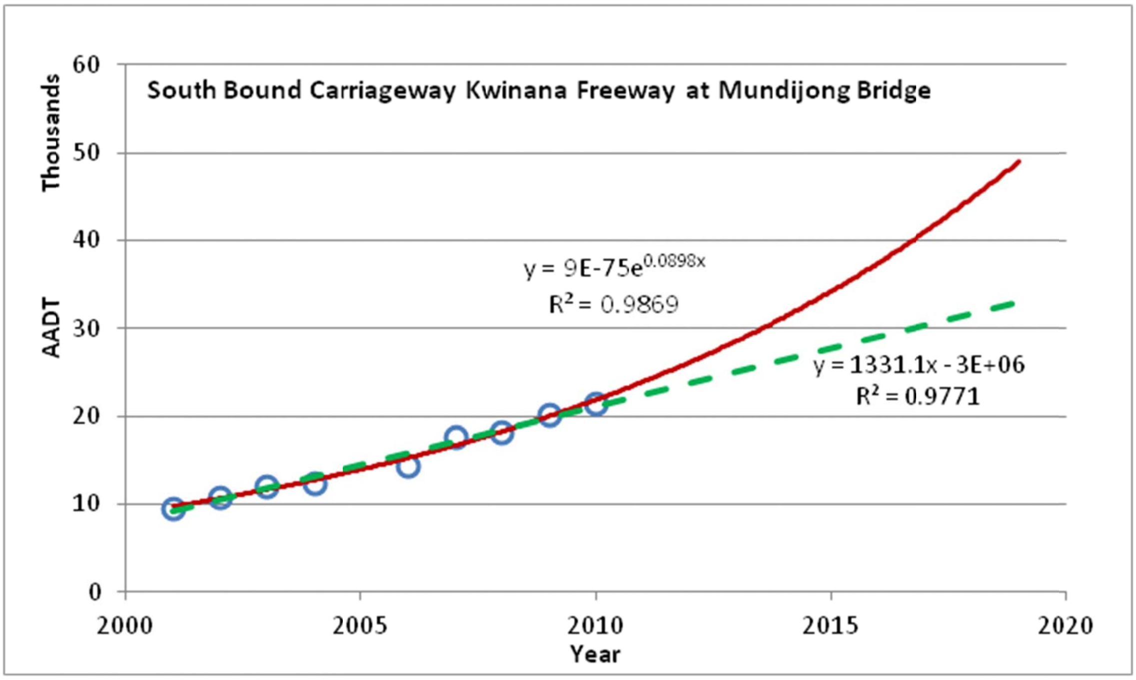

Figure 6: South bound Kwinana Freeway, Mundijong Bridge, outer metropolitan location

This segment of road has been included to highlight the potential problems with compound traffic growth assessment and the potential differences between the two methods. The traffic data gathered since opening of the pavement in 2001 shows that the traffic growth rate is following a compound traffic growth curve with nine year of traffic data supporting a very high compound growth rate of over 9%. The graph shows that either method of regressing the data is mathematically sound with the exponential regression having the best R^2 value. The designer has no simple way of determining when to reduce the compound growth rate and introduce a new lower growth rate in keeping with regional traffic growth expectations. The linear traffic analysis appears to effectively reduce the traffic growth ratio each year.

At this location the Kwinana Freeway is a four lane (two carriageways) major arterial freeway carrying commuters and freight between Perth to Rockingham, Mandurah and the South West of Western Australia. It was opened to traffic in 2001. The first year AADT of 9576 and the compound growth rate since opening is 9.5% or alternatively, a linear growth rate linear growth rate of 1,331 vehicles per year. The long term traffic counts from the Kwinana Freeway at the Narrows Bridge and Great Eastern Highway suggest that the linear growth path is the most likely path for the increasing traffic to follow. Further if the traffic was to continue at the observed rate of 9.5% growth for the next 10 years the pavement would need to carry 40,000 vehicles per day in 2017, whereas the linear growth model would predict this level of traffic will not occur until 2025. This high compound traffic growth rate accentuates the difference in two methods for calculating the 40 year design traffic with the linear traffic growth rate method predicting only 25% of the DESA's compared the compound traffic growth rate method.

The design lane traffic using the two growth rate methods.

	Compound	Linear AADT/year
Growth Rate	9.5%	1331
20 year DESA's	7.0×10^7	3.7×10^7
40 year DESA's	4.9×10^8	1.0×10^8

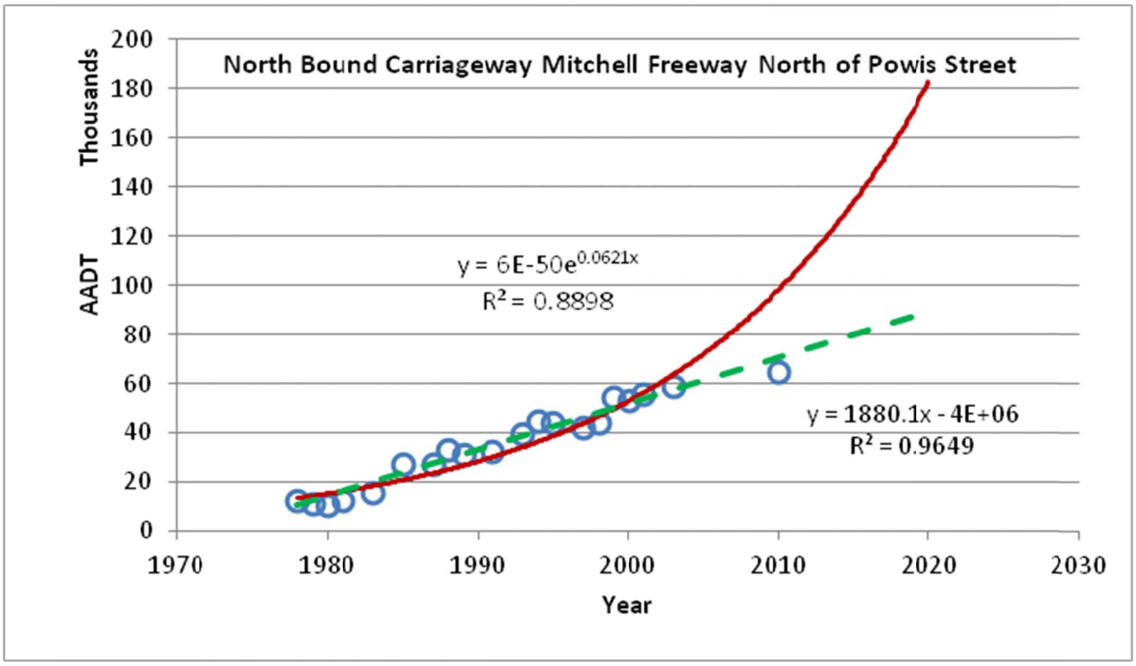

Figure 7: North bound Mitchell Freeway, Powis Street, inner metropolitan location

This segment of the Mitchell Freeway is locate near the Perth CBD and was originally constructed as a four lane freeway in about 1975. The north bound carriageway was relocated to accommodate a passenger railway line and both carriageways were widened to three lanes in 1992. The graph shows that the linear regression of the traffic data provides the best method of predicting the future traffic growth and the high compound growth rate percentage value highlights the differences in the two methods.

The road serves mainly as a commuter route connecting the northern suburbs to the Perth CBD. It has seen a steady growth in traffic with a calculated compound growth rate of R_c = 6% over 30 year of traffic data however the traffic data does not appear to follow the compound growth line. The linear growth rate = 1880 AADT per year shows a better fit to the observe traffic data. Extending the two traffic growth models to 20 year and 40 years shows almost three times the difference in the calculated design traffic.

The design lane traffic using the two growth rate methods.

	Compound	**Linear AADT/year**
Growth Rate	6.4	1880
20 year DESA's	9.7×10^7	6.0×10^7
40 year DESA's	4.3×10^8	1.5×10^8

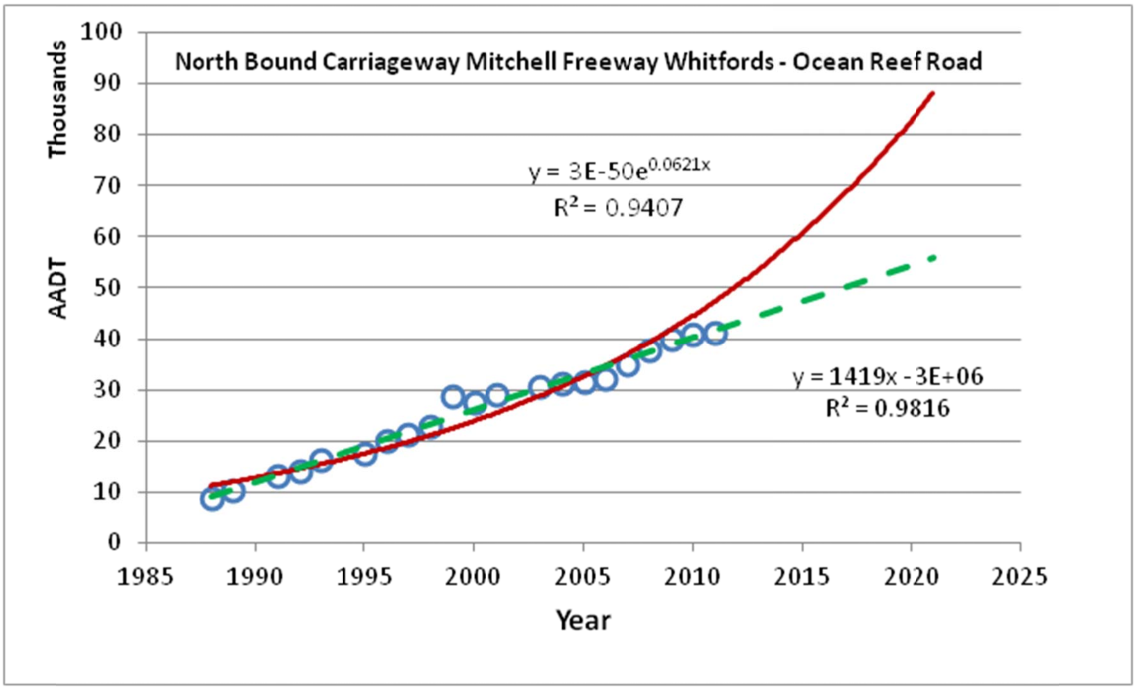

Figure 8: North bound Mitchell Freeway at Ocean Reef Road, metropolitan location

This section of the Mitchell Freeway is located about 20 kms north of the Perth CBD and the traffic data extends back to the year it was opened to traffic in 1986. The north bound carriageway was constructed as a two lane divided freeway and it is proposed to widen it to three lanes in 2013. The graph shows some variations in the traffic volumes due to extensions to the Mitchell Freeway however the data appears to remain on a relatively linear path over the 25 year of available traffic data. The relatively high slope of the linear traffic growth and the low initial year one traffic volume causes a relatively high compound traffic growth rate the be calculated.

It appears coincidental that the compound traffic growth rate for this section of the Mitchell Freeway is the same as the Mitchell Freeway at Powis Street, refer Figure 7. Both compound growth rates are equal to 6.4%, however the linear traffic growth rate of the Mitchell Freeway at Powis Street is 32% more than at Ocean Reef Road. At this location the compound traffic growth model predicts a design traffic 2.5 time greater than the linear traffic growth model.

The design lane traffic using the two growth rate methods.

	Compound	Linear AADT/year
Growth Rate	6.4	1419
20 year DESA's	7.2×10^7	5.0×10^7
40 year DESA's	3.2×10^8	1.3×10^8

FURTHER RESEARCH

With the new generation of permanent traffic counting equipment such as TIRTL (The Infra-Red Traffic Logger) and Piezo WIM (Piezoelectric Sensors – Weigh-in-Motion) sites traffic growth rates for each class of vehicle will be possible. Classified traffic data from these facilities located on selected sites around Perth will be accumulated to develop an understanding between the growth rates of each class of vehicle compared to the overall total traffic volume.

Analysis of the four years of classified TIRTL traffic data since the installation on the Mitchell Freeway at Ocean Reef Road site suggests that the heavy vehicle growth rates are significantly higher than the total traffic. It is thought that this difference could be caused by significant congestion has encouraged commuter motorists to travel alternative routes while commercial and the larger permit base heavy vehicles are constrained to the freeways and highways. Further research and classified traffic data from a number of sites will need to be investigated to determine the differences between heavy vehicle traffic growth and the total traffic growth rates.

CONCLUSION

It is fortunate that we have gathered and analysed over 30 years of traffic data across several roads in the Perth metropolitan area. The traffic counts on most roads show that the long term traffic growth can be modelled with a linear growth trend. It was also observed that the population of Perth was also following a linear trend between 1956 and 2006 and it can be surmised that the long term traffic growth rate are closely related to the population growth rate.

It should remain very important for road authorities and road asset owners to continue to collect and store long term traffic data across their road networks to enable sound engineering and planning decisions to be made for the design and planning of new pavements and the maintenance of existing pavements.

Where traffic compound growth rates were calculated at less than 3% the differences between the compound growth rate model and the linear growth rate model were relatively small so the variation in pavement designs outcomes is expected to be small. Where traffic compound growth was calculated at greater than 3% it is recommended that the designer consider whether this is realistically sustainable or weather it would be more appropriate to use a linear traffic growth model for the purposes of calculating the design traffic for pavement design. This is particularly important in pavement decisions for higher traffic urban arterial roads where population growth and traffic growth may be constrained.

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AUTHOR BIOGRAPHIES

Simon Kenworthy-Groen has over 20 years of experience working as a geotechnical and pavements engineer on projects throughout Western Australia. He has spent the last six years working as a pavement engineer with Main Roads WA undertaking pavement failure investigations and pavement design projects. Simon is passionate about investigating engineering problems and establishing sound factual information as the basis for his engineering work.

