Climate Change Impact on the Pavement Maintenance and Rehabilitation Costs associated with the Australian National Highway Network.

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EXTENDED ABSTRACT

Austroads and the Commonwealth Federal Department of Transport and Regional Services (DoTRS) engaged CSIRO, the Australian Road Research Board (ARRB) Transport Research, the Monash University Centre for Population and Urban Research and the Australian Bureau of Agricultural and Resource Economics (ABARE) to undertake a project to examine likely future climate change and population scenarios for the whole of Australia during the 21st Century, with the aim of investigating the effects on major road infrastructure, as represented by the Australian National Highway network. The project and final report titled “Impact of Climate Change on Road Infrastructure” (Austroads, 2004) was coordinated by the Bureau of Transport and Regional Economics (BTRE).

Climate change can have direct and indirect impacts on road infrastructure. Rainfall changes can alter moisture balances and influence pavement deterioration. In addition, temperature can affect the aging of bitumen resulting in an increase in embrittlement (cracking) of the surface chip seal, with a consequent loss of waterproofing. The result is that surface water can enter the pavement causing potholing and fairly rapid loss of surface condition. More frequent reseal treatments will ameliorate the problem, but at a cost to road agencies. Changes in temperature and rainfall patterns can interact where higher temperatures increase cracking, compounding the effects of increased rainfall.

The indirect impacts of climate change on roads are due to the effects on the location of population and human activity altering the demand for roads. Road infrastructure is a long-lived investment. Roads typically have design lives of 20 to 40 years and bridges of 100 years. An understanding of the expected impacts of future climate change by road planners, designers and asset managers could engender considerable cost savings in the long term. At the broad strategic level, if road providers are forewarned of any costly likely future effects on existing infrastructure, they can better prepare to deal with them.

The study compared pavement maintenance and rehabilitation costs for a year 2100 climate projection (based on a high emissions scenario; SRES A2) and “climate-adjusted” population projections, with present day levels, and determined the following major outcomes:

- Nationally, there is a small decrease (between 0% and -3%) in the required pavement maintenance and rehabilitation budget based solely on climate change factors. This result reflects the generally warmer and drier Australian climate (the reduced precipitation lowers the rate of pavement deterioration).

- Annual pavement maintenance and rehabilitation budget is estimated to increase by around 30% (considering both the influences of climate change and transport demand changes).

- There are significant regional variations in the change of pavement maintenance and rehabilitation costs as a result of climate variation and population and transport demand trends. For example, increases of over 100% and 50% are projected for the Northern Territory and the state of Queensland respectively, due to the larger population increases and wetter climate expected within this state and territory.

Limitations of the analysis include that the effects of weather extremes such as severe storms and flooding, which are projected to increase both in number and intensity, have not been taken into account. Due to the computational requirements of the study, it was only possible to develop one high resolution regional climate pattern for one climate change scenario, instead of exploring the range of possible regional outcomes.

1. INTRODUCTION

There is an increasing body of evidence that the earth's climate is changing. Temperature data covering the worlds oceans and land areas, show a warming of around 0.8C since 1910. The past decade has witnessed 9 of the 10 warmest years on record (Jones, 2005). Corrected satellite measurements of lower atmospheric temperature (obtained since 1979) show a warming of 0.18C per decade (Mears and Wentz, 2005). The source of the most reliable climate change information is the Intergovernmental Panel on Climate Change (IPCC). The report (IPCC, 2001), was written by over 2500 climate experts representing all nations from around the world. They assessed material published in reputable scientific journals, reports and books.

There is strong evidence and a strong scientific consensus that climate change due to increasing concentrations of human-produced greenhouse gases is an issue requiring serious consideration of policy options from mitigation through to adaptation. Sound actions based on the best-available information are always likely to produce better outcomes than ignoring a problem.

Climate change can have direct and indirect impacts on road infrastructure. The direct impacts are due to the effects of the environment; chiefly rainfall and temperature. Rainfall changes can alter moisture balances and influence pavement deterioration. Temperature can affect the aging of bitumen resulting in an increase in embrittlement of the surface chip seals that represent more than 90% of the rural sealed roads in Australia. Embrittlement of the bitumen causes the surface to crack, with a consequent loss of waterproofing of the surface seal. The result is that surface water can enter the pavement causing potholing and fairly rapid loss of surface condition. More frequent reseal treatments will ameliorate the problem, but at a cost to road agencies. Changes in temperature and rainfall patterns can interact where higher temperatures increase cracking, which compounds the effects of increased rainfall.

The indirect impacts of climate change on roads are due to the effects on the location of population and human activity altering the demand for roads.

This study examines changes in road agency costs of pavement deterioration on major road infrastructure, as represented by the Australian National Highway network (NHN). These possible changes result from projected climate change, both from temperature and rainfall, as well as from climate-related changes to demographics and therefore road usage. The effects of salinity are also examined as high water tables affect the structural strength of pavements. Important climate change issues not examined in this study are flood heights and frequencies, as well as the location and design of roads and bridges. Other effects that were not considered are sea level rise and increased occurrence of storm surges, which will affect roads in coastal areas.

Roads typically have design lives of 20 to 40 years and bridges of 100 years. This infrastructure is a long-lived investment, and an understanding of the expected impacts of future climate change by road planners, designers and asset managers could engender considerable cost savings in the long term. Any assistance and forewarning provided to road providers of potential and costly future effects on existing infrastructure, can better prepare them for a considered response. This paper provides an overview of the study and presents some of the major findings.

2. PROJECT PLAN

The project aims were to:

- provide a "high global emissions" assessment of likely local effects of climate change for all Australia for the next 100 years, based on the best scientific assessment currently available;
- assess the likely impacts on patterns of demography and industry, and hence on the demand for road infrastructure;
- identify the likely effects on existing road infrastructure and potential adaptation measures in road construction and maintenance; and
- report on policy implications arising from the findings of the project.

A number of organisations with expertise in different areas contributed to final report:

- The CSIRO Division of Atmospheric Research (now the Division of Marine and Atmospheric Research) produced detailed Australia-wide projections of climate (50 km horiz. resolution) for the 21st century. These were passed on to three consultants to assess the implications.
- The Monash University Centre for Population and Urban Research investigated the likely effects on population settlement patterns and demographics.

- ARRB Transport Research examined the implications for road pavement deterioration in the National Highway System.

- The Australian Bureau of Agricultural and Resource Economics (ABARE) forecast changes to salinity and agricultural production in the Murray-Darling basin, with the likely effects on road infrastructure.

The study project was coordinated by the Bureau of Transport and Regional Economics (BTRE) and they authored the Executive Summary and the Policy Implications sections.

3. CLIMATE CHANGE PROJECTIONS

The IPCC Special Report on Emissions Scenarios [SRES] (IPCC, 2000) produced 40 future emissions scenarios for greenhouse gases and sulfate aerosols based on estimates of population, energy consumption, energy efficiency, gross world product, energy resources and reserves. The project management team selected one of the higher emissions scenarios, 'SRES A2', which provided a radiative forcing signal for the 21st century in the CSIRO Mark 2 atmospheric-ocean global climate model (AOGCM) in order to obtain a significant increase in greenhouse gas emissions during the 21st century and a strong contrast with current conditions. This scenario is predicated on a global population of around 15 billion in 2100 and has no special status as a likely future. Under the A2 scenario, the rate at which carbon dioxide is released into the atmosphere grows steadily over the next 100 years, increasing nearly fourfold. These emissions in turn provide a strong radiative forcing signal for the establishment of regional climate change patterns over the Australian continent.

CSIRO's AOGCM is a comprehensive general circulation model that contains atmospheric, oceanic, sea-ice, and biospheric sub-models (Gordon et al., 2002). For the atmospheric model, the horizontal grid resolution was about 200 kilometres, with a suite of geophysical parameters at both the surface and the 9 atmospheric layers (such as temperature, air pressure, wind velocity, water vapour content and so on) calculated with a time step of 30 minutes. The numerical integration was run with a historic radiative forcing representing 1870 to 1990 and the SRES A2 scenario from 1990 to 2100 (230 years in total). Results from the CSIRO's AOGCM were used to 'nudge' CSIRO's atmospheric Conformal-Cubic General Circulation Model (GCM) (McGregor, 2005). In this model, the grid is stretched to provide high resolution over Australia (about 50 kilometres), but lower resolution for the rest of the world (around 800 kilometres on the far side of the globe). To avoid errors introduced by the lack of detail over the rest of the world, winds outside of Australia were 'nudged' to make them consistent with winds in the AOGCM. This technique allows for the determination of the "regional pattern" or "regional sensitivity" of the global climate change.

Modelled outputs were monthly means of average, maximum and minimum temperature, precipitation, solar radiation, and potential and actual evaporation for each grid point. These were expressed in terms of local temperature change or percent for rainfall/radiation/evaporation change *per degree of global warming*. Expressing them per degree of global warming means that, for any IPCC global warming scenario, a local future scenario can be derived for any grid point over the next 100 years. Also, from the upper and lower limits and average of the envelope of IPCC global warming scenarios, one can obtain ranges and mid-points of changes over time.

Overall, the projections indicate that Australia is expected to become hotter and drier. The key results for temperature and rainfall are presented in graphical form in Austroads (2004). The SRES A2 simulation employed in this study results in Australian average annual temperatures increasing by between 2º to 6ºC by 2100. Warming will not be uniform with Tasmania and coastal zones least affected and inland areas most affected. This compares with the results of an earlier study over the Australian continent examining many scenarios and many general circulation models (CSIRO 2001) that indicated annual average temperatures rose by 1.0 to 6.0ºC over most of Australia by 2070.

This simulation indicates a general reduction in rainfall over most of the continent, except for the far northern coastal fringe where there will be significant increases.

In places where average rainfall increases, there will be more extremely wet years. There are also likely to be tropical cyclones of greater intensity, leading to an increase in the number of severe oceanic storm surges in the north. There will be more frequent, or heavier, downpours. Conversely, there will be a higher frequency of droughts in regions where average rainfall decreases. Evaporation is projected to increase over most of the country, adding to moisture stress on plants, and to drought.

4. IMPACTS ON POPULATION AND SETTLEMENT PATTERNS

The Monash University Centre for Population and Urban Research developed population projection scenarios (for Australia, as well as for the States and major metropolises), based partly on Australian Bureau of Statistics (ABS) projections and supplemented by the Australian National University (ANU) demographic projection software. The factors shaping Australia's population outlook and settlement patterns: fertility, mortality, and international and internal migration movements were considered.

Adjustments were made to the projections for eight major metropolitan regions to reflect the impact of forecast climate change. These adjustments were based on expert judgement supported by a human "comfort index" (Phillips and Crowe, 1984; Matzarakis et al., 1999), which is a function of temperature and humidity. The methodology assumes that a "comfortable climate" is a major driver of internal migration, as the life-style promise appears to be the basis for the current attraction of (and internal migration to) Cairns, the Gold and Sunshine coasts (i.e. climate is a major factor).

The analysis assumes that the total fertility rate will fall to 1.6 and stabilise at that level and that net overseas migration will be 90,000 per year over the 21st century. The population projected on these assumptions grew during the 21st century from 19.1 million in 2000 to 27.3 million in 2100. Industry restructuring trends in Australia strongly favour further metropolitan population concentration, so there will be a greater concentration of Australia's population in the four major metropolises (Sydney, Melbourne, Brisbane and Perth). There will be a significant increase in the share of Australia's population living in Queensland. Projections were prepared for each of Australia's metropolises, which assessed the demographic implications of these assumptions. With Australia generally becoming hotter and drier, total net migration from overseas is forecast to be lower.

5. IMPACTS ON ROAD TRANSPORT DEMAND

ARRB Transport Research estimated the impact of the climate-adjusted population projections on the demand for road use. Origin–destination population factors were developed between the eight metropolitan areas assessed following a gravity model approach. Passenger and freight tasks were considered separately. Car ownership per capita was forecast to reach saturation at 550 cars per 1000 persons around 2030. Adjusting for changes in per capita ownership, car travel increases were forecast from population growth figures.

The freight task was estimated using the same origin–destination population factors combined with a predicted increase in freight per capita. Road freight *per capita* is forecast to continue rising until 2060 and thereafter to stabilise. It was assumed that, in the future, fewer vehicles would be needed to transport the same volume of freight, compared to the number required in the year 2000. This is due to a combination of larger vehicles in the future, higher utilisation rates, and higher mass limits. The proportions of B-doubles in the truck fleet and mass limits are rising, but these trends were not assumed to continue beyond 2020. This study didn't consider changes in freight movement as a result of changes in primary production that may arise as a result of climate changes.

6. IMPACT ON PAVEMENT PERFORMANCE

The pavement modelling was undertaken using two approaches. The first was the ARRB TR pavement lifecycle costing (PLCC) model and the second using the Highway Development and Management 4 (HDM4) model. The former was used to assess pavement performance at a network level and the latter to assess selected road lengths at a more detailed level.

Climate in both models is represented by the "Thornthwaite moisture index" (Thornthwaite, 1948), which is a function of precipitation, temperature and potential evapotranspiration. The latter depends on a range of factors including temperature and length of daylight hours. Roads in areas with higher value for the Thornthwaite index will deteriorate faster than those with a lower value for the same traffic loading. A warmer and wetter climate leads to a higher rate of pavement deterioration, both as function of time and as a function of the pavement load (unit: equivalent standard axles; ESAs).

Across Australia, the Thornthwaite index values for the current climate vary from +100 on Cape Yorke Peninsula to –50 in central Australia. Thornthwaite index values were calculated for the 21st century (up to year 2100) utilising the CSIRO climate projections, and then interpolated for locations on the National Highway System. Figure 1 shows the change in the Thornthwaite index over the Australian region, for 2100 relative to the

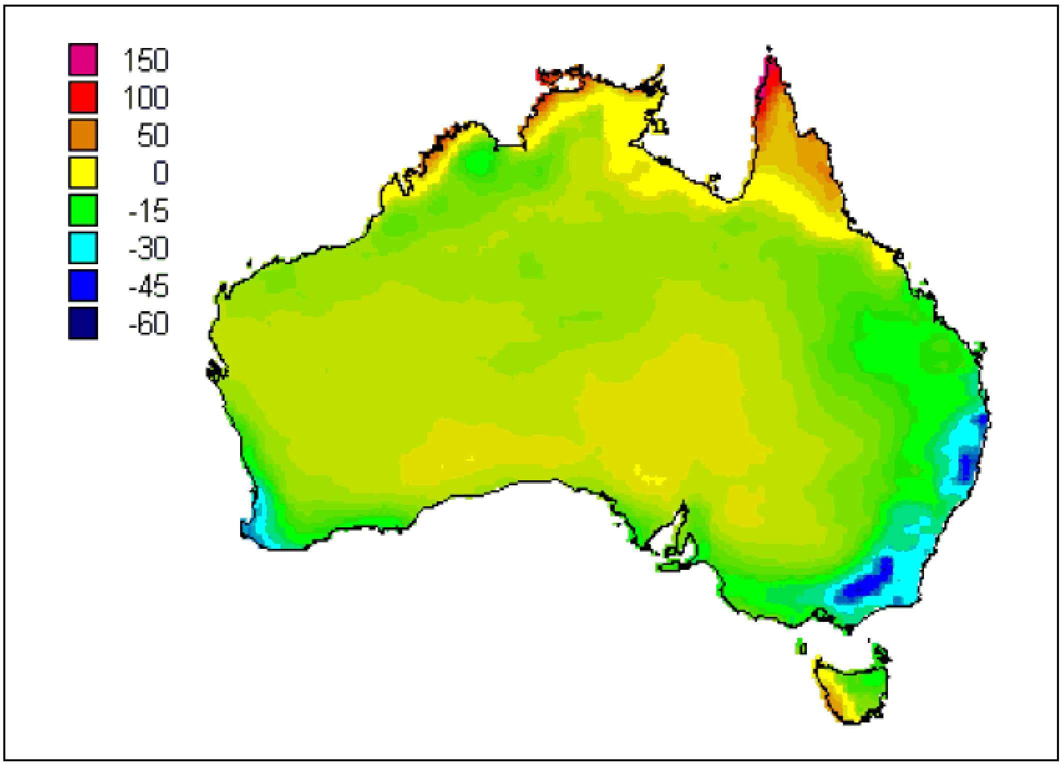

Figure 1. Changes in the Thornthwaite Index (year 2100 relative to 2000) under SRES A2 scenario

current climate under the SRES A2 climate change scenario. The generally warmer and drier climate leads to negative changes in Thornthwaite index values over most of the continent. Areas of greatest negative change include the south-west of WA, north-east Victoria, and southern NSW. The greatest positive changes occur in south-west Tasmania and the top end of Queensland. Little change is projected in the central area of Australia.

The PLCC model estimates life-cycle road agency costs (maintenance and rehabilitation) and road-user costs (travel time and vehicle operation) based on roughness predictions for a set of defined road categories. The present value of combined road agency and user costs is calculated for a 60-year analysis period assuming a 7 per cent real discount rate. The model selects treatment options and timings to minimise the present value of costs subject to any specified constraints on maximum roughness or annual agency budget limits. To analyse the entire National Highway System, the network was split into 60 different road 'sections', each section having similar climate characteristics, traffic levels, vehicle mix and pavement characteristics.

The HDM4 analysis was also undertaken on the basis of minimising the present value of the sum of road agency and user costs. The main difference between the PLCC and HDM4 approaches to maintenance is that the latter employs a much more detailed pavement deterioration algorithm. HDM4 uses a set of interdependent algorithms covering roughness, rutting, cracking, potholing, ravelling, strength and so on, and consequently has much more detailed data requirements. By contrast, the deterioration algorithm in the PLCC model has roughness as a function of pavement age, cumulative ESAs, the Thornthwaite index and annual average maintenance expenditure as a surrogate for agency maintenance treatments.

Eight road segments, one from each state and territory, located in or near a metropolitan area, were analysed in detail using the HDM4 model. Site-specific predicted changes in Thornthwaite index, annual average daily traffic (AADT) and per cent heavy vehicles were used in the model.

As pavement deterioration in the models depends on both the Thornthwaite index and load (ESAs), both the direct and indirect effects of climate change on pavements come into play. Although trucks and not cars add to ESAs and so contribute to pavement deterioration, car traffic has an impact on the timing and types of maintenance treatments where the model is set up to minimise the present value of the sum of road agency and road user costs. Since increased roughness adds to road user costs for cars, higher volumes of car traffic will justify maintaining the road at a higher standard leading to greater agency costs.

7. IMPACT ON SALINITY IN THE MURRAY–DARLING BASIN

Large parts of Australia are affected by salinity, which affects roads in two ways. High water tables reduce the structural strength of pavements, and salt rusts the reinforcement in concrete structures. Precipitation and evapotranspiration are the main determinants of surface and ground-water flows, and it is via these variables that climate change will have an impact on salinity levels.

ABARE incorporated the CSIRO projections into its Salinity and Landuse Simulation Analysis (SALSA) model of the Murray–Darling basin, to determine the effects of climate change. The area covered represents a substantial part of the Australian landmass and the methodology could be employed for other catchments. The model consists of a network of land management units linked through overland and ground water flows. The hydrological component incorporates relationships between rainfall, evapotranspiration, surface water run-off, irrigation, the effects of landuse change on ground water recharge and discharge rates, and the processes governing salt accumulation in streams and soil. The climate projections were incorporated into the model via two variables: rainfall and evapotranspiration (Alexander and Heaney, 2003).

Other studies have examined the effects of rising water tables and dryland salinity on major infrastructure including roads. The interested reader is referred to the work of the National Land and Water Resources Audit (www.nlwra.gov.au).

Under the climate change scenario, the present value of net production revenue falls by 11 per cent between 2000 and 2100. The effects of climate change vary considerably across catchments, with the loss in agricultural revenue being generally higher in the Darling River tributaries. A reduction in available surface water flows results in a proportional reduction in the volume of water available for irrigation. Land engaged in the lowest returning irrigated activity in each catchment would be switched into lower returning dryland activities. Catchments predominantly engaged in high value cropping, such as cotton production or horticulture would be particularly affected by reductions in available water. There is less surface water to dilute existing salt loads leading to increased salt concentration in both the Darling and Murray Rivers in comparison to the baseline. In addition to reducing yields from irrigated production, increased salt concentration of surface water flows will also have an impact on infrastructure (eg. roads and bridges) and the riverine environment.

8. RESULTS

The drier climate leads to negative changes in Thornthwaite index values over most of the continent. Areas of greatest negative change include the south-west of WA, north-east Victoria, and southern NSW. The greatest positive changes occur in south-west Tasmania and the top end of Queensland. The index in the central area of Australia is projected to change little.

The PLCC model produces separate results for both maintenance and rehabilitation of pavements. The maintenance expenditures refer to pavement-related expenditure on routine and periodic maintenance activities, such as pothole patching, kerb and channel cleaning, patching, surface correction and resealing.

Table 1 shows that the Northern Territory and Queensland experience large cost increases, primarily driven by population growth, though the forecast wetter climate in the far north also plays a role. The decline in South Australia reflects the smaller population and drier climate.

Nationally, there is a small decrease (between 0% and -3%) in the required pavement maintenance and rehabilitation budget based solely on climate change factors. Annual pavement maintenance and rehabilitation budget is estimated to increase by around 30% (considering both the influences of climate change and transport demand changes). There are significant regional variations in the change of pavement maintenance and rehabilitation costs as a result of climate variation and population and transport demand trends.

Results from the HDM4 analysis are not presented here. As with the PLCC model, the results show that road agency costs can change considerably under the 2100 traffic and climate scenario. Most of the change in road user costs is associated with increases in traffic. Environmental effects of climate change on agency and road user costs are very small. Virtually all of the changes from the HDM4 analysis come about from population growth leading to traffic increases.

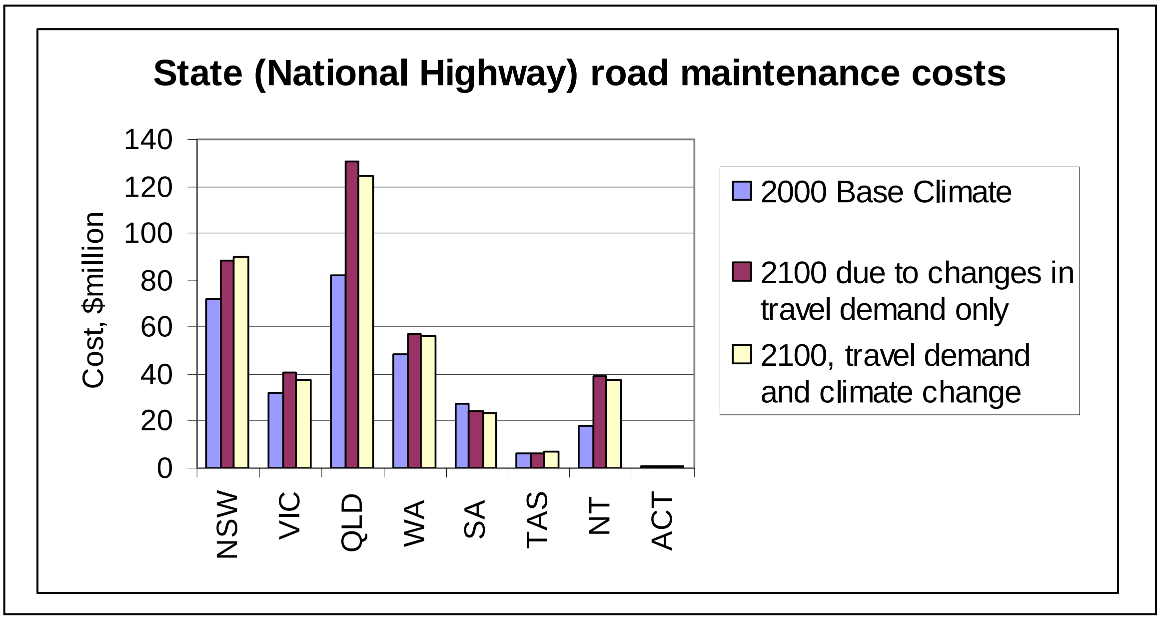

Table 1. Agency Costs state-by-state using PLCC model (SRES A2 climate change scenario)

9. DISCUSSION

Even when considering a "high global emissions" climate change scenario, the impact due to climate on the pavement maintenance and rehabilitation costs is very small (nationally) in comparison to the demography and industry impacts. However, there are important regional impacts which should be considered as part of the forward planning process.

Limitations of the analysis include that the effects of weather extremes such as severe storms and flooding, which are projected to increase both in number and intensity (IPCC, 2001), have not been taken into account.

In addition, reliable and accurate calibration of the pavement deterioration algorithm for conditions in each state has not yet been completed , and no allowance has been made of expansion of the number of lane-kilometres to cater for increased demand for road capacity. A greater surface area of pavement will add to maintenance costs, but spreading the truck traffic over a greater surface area should counteract this effect.

Design pavement strengths have been assumed to remain unchanged. Where forecast pavement deterioration is expected to be higher due to truck traffic or the environment, road agencies would be expected to build stronger pavements, substituting capital for maintenance costs. The assumption of constant pavement strengths implies that if heavy vehicle traffic changes in response to climate change (for example through changes in population settlement patterns), then existing pavements will reach the end of their useful lives earlier requiring rehabilitation, also increasing costs to road agencies.

It has also been assumed that road agencies will develop maintenance programs to minimise the present costs. Budget constraints may lead to short-term underspending on maintenance at the expense of higher costs in the long term. Social and equity considerations may lead to less trafficked parts of the NHN being maintained at standards that cannot be economically justified.

10. CONCLUSIONS

The study compared pavement maintenance and rehabilitation costs for a year 2100 climate projection (based on a high emissions scenario, SRES A2) and "climate-adjusted" population projections, with present day levels, and resulted in the following major outcomes:

- Nationally, there is a small decrease (between 0% and -3%) in the required pavement maintenance and rehabilitation budget based solely on climate change factors. This result reflects the generally warmer and drier Australian climate (the reduced precipitation lowers the rate of pavement deterioration).

- Annual pavement maintenance and rehabilitation budget is estimated to increase by around 30% (considering both the influences of climate change and transport demand changes).

- There are significant regional variations in the change of pavement maintenance and rehabilitation costs as a result of climate variation and population and transport demand trends. For example, increases of over 100% and 50% are projected for the Northern Territory and the state of Queensland respectively, due to the larger population increases and wetter climate expected within this state and territory.

Limitations of the analysis include that the effects of weather extremes such as severe storms and flooding, which are projected to increase both in number and intensity, have not been taken into account. Due to the computational requirements of the study, it was only possible to develop one high resolution regional climate pattern for one climate change scenario, instead of exploring the range of possible outcomes.

11. ACKNOWLEDGEMENTS

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