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ASSESSING THE IMPACTS OF CLIMATE CHANGE ON ROAD INFRASTRUCTURE

*Zeshen Shao[1], Graham Jenkins[1] and Erwin Oh[1]

[1]Griffith School of Engineering, Griffith University, Australia

*Corresponding Author, Received: 4 March 2017, Revised: 25 March 2017, Accepted: 10 April 2017

ABSTRACT: There is an increasing evidence that the earth's climate is changing with some of the changes attributable to transport infrastructure. Climate change can have impacts on road infrastructure. The direct impacts can be due to the effects of environment. Temperature can affect the aging of bitumen resulting in an increase in brittle failure of the surface seals that represent more than 90% of the rural sealed roads in Australia. Further, rainfall changes can alter moisture balances and influence pavement deterioration. Brittle failure of the bitumen causes the surface to crack, with a consequent loss of waterproofing of the surface seal. The result is that surface water will enter the pavement causing potholing and will cause rapid loss of surface condition. More frequent reseal treatments will overcome the problem, but this is at a higher cost to road agencies. Road infrastructure is a long-lived investment. An understanding of the expected impacts of future climate change by road designers, asset managers and planners, could produce considerable cost savings in the long term. This research aims to provide an assessment of likely effects on climate change for South East Queensland region in the next 90 years, and further identify and assess the likely effects of climate change on road pavement. It can be concluded that, climate change in South East Queensland does play a role in lower deterioration rates. The findings suggest that decreasing rainfall (decreasing TMI) will slow flexible pavement deterioration. However, increases in temperature are likely to cause materials to expand to affect pavement deterioration rates.

Keywords: Climate Change, HDM-4 Model, Pavement, Road Infrastructure.

1. INTRODUCTION

The issue of climate change has been recognized globally as an issue of utmost concern and the threat of climate change poses problems to all nations of the world [1]. Australia is a hot and dry country and as a result the continent is particularly vulnerable to increases in temperature due to climate change [2].

The South East Queensland (SEQ) is Australia's fastest growing metropolitan region and the region's population is approximately 3 million and an additional 1.1 million new residents are expected by 2026 [3]. An adequate and efficient road network is amongst the most important infrastructural features of SEQ region.

The road network in Queensland is about 180,500 kilometres in length. The state-controlled network is 33,337 kilometres long and has an estimated replacement value of $54.9 billion [4]. This makes it the largest publicly-owned physical infrastructure asset in Queensland. This road network is most critical in urban areas where access and mobility for transport, freight, and emergency services are vital.

As road pavement infrastructure is a long-lived investment and roads typically have design lives of 20-40 year, an understanding of the localized expected impacts of future climate change could engender considerable cost savings in the long term [5]. However, relatively little research has been completed to investigate the potential impacts of climate change on pavement infrastructure of SEQ despite the dependence of this region's economic and social activity on road transport.

This paper recognized that road infrastructure in SEQ region will face great challenges from climate change because of the implications for the design, construction and maintenance of road pavements. Pavements are designed based on moisture and temperature patterns reflecting the history of the local climate. With projected climate changes over the next several decades, a pavement could be subjected to very different climatic conditions over the design life than was originally expected. Changes in rainfall, temperature and evaporation patterns can alter the moisture balances in the pavement foundations and also affect the aging of the bitumen road surfacing layers [6]. Several governments and organisations have already started facing the problem by financing studies and projects with the aim of finding possible ways to precaution [7]. However, the nature and scale of climate change impacts on road pavement will depend on a wide range of variables and will not be equally distributed across the landscape [7]. Therefore, a localized comprehensive study of SEQ is required.

2. CLIMATE DEFINITION

2.1 Climate Tool

An essential first step in this study is the construction of a plausible range of future climate conditions, as they are one of the main inputs for pavement deterioration models that are responsible for calculating the potential impacts of climate change. Therefore, quality climate data play a significant role in this study by providing a fundamental basis for investigating the impact of future climate on road pavement performance. With access to complete historical data, the road pavement/climatic interaction can be better understood. High quality climate data is also essential to building, validating and calibrating pavement performance models. Besides, quality predictions of future pavement performance are impossible without knowledge of future climatic conditions.

Historical climate data is traditionally obtained at weather stations located sporadically around Australia it is complicated to identify climate data for a point along a road. A more difficult problem is forecasting or simulating future trends due to climate change [8].

In this study, Austroads Climate Tool is used to obtain historical and projected climate data of selected locations in SEQ. In 2010, Austroads [8] developed a Climate Tool which provides easier access to both historical and simulated future data from 1960 to 2099. The historical data of Climate Tool was retrieved from the Bureau of Meteorology database and arranged into a format that allows query retrieval based on GPS information. The future climate data is obtained from Commonwealth Scientific and Industrial Research Organisation (CSIRO) prediction based on Atmospheric Research and various severity scenarios [9].

The climate tool was designed to extract the most common climate data required by a typical user. The user can query GPS co-ordinates anywhere within form 114.00 to 154.00 for longitude and -10.50 to -43.50 for latitude, covering the whole of Australia including Tasmania and surrounding islands [8].

Climate change scenarios are plausible projections of future climate conditions. As such, they contain two major sources of uncertainty: the differences between the projections of different climate models, which reflect our incomplete understanding of all of the physical processes involved; and the wide variation in predictions of the future amount of greenhouse gases in the atmosphere [9].

The range of climate projections from the Austroads Climate Tool presented as three levels of simulated severity. This severity is based on the CSIRO estimates of query of the effects of climate change on rainfall and temperature. The three severity levels are lower, average and upper. In this study, the upper severity is chosen in order to investigate the worst case of impact of climate on pavement deterioration. Although the severity of climate may have small effects on individual pavement performance, it can have a significant effect on a road network over its life [8, 10].

2.2 Climate Data Extracting

The climate data can be only extracted based on specific GPS co-ordinate. Therefore, the GPS locations of different Long Term Pavements Performance (LTPP) sites for climate analysis purpose have to be defined firstly. Due to the fact that the differences of GPS co-ordinates among the LTPP sites within the same city region are minor, an average GPS value of LTPP sites located in the same region is adopted for climate analysis of corresponding region. For the purpose of this research, the 'future' climate will be defined by analysing projections of climate based on three different time series in 30-year increments.

Climate in a narrow sense is commonly defined as the "average weather" over a long period of time. The classical averaging period is 30 years, as defined by the World Meteorological Organization (WMO) [1]. Therefore, these three future climate periods are 2008 to 2040, 2041 to 2070, and 2071 to 2099.

2.3 Climate Data Processing

The climate data extracted from Climate Tool have to be processed into proper forms as input of Highway Development and Maintenance Management System (HDM-4). The major climate inputs required by HDM-4 are: Thornthwaite moisture index (TMI), mean annual temperature (MAT), mean monthly precipitation (MMP), average monthly temperature range (MTR). Procedure of climate data processing is described in the following sections.

TMI and MAT data can be obtained from Climate Tool database directly. Historical TMI and MAT were calculated by taking averages of data from 1960 to 2007. The simulated future TMI and MAT were calculated by taking averages of data in 30-year increments from 2008 to 2099. MMP data requires further processing. Historical monthly precipitation data presented based on every single month of each year from 1960 – 2007. Therefore, the historical MMP is calculated by taking the average of monthly precipitation data from January to December of every single year.

The simulated future MMP is not provided but only the annual precipitation data so that the future MMP is calculated by taking average of the annual data. MTR is not provided by Climate Tool directly. It is calculated based on maximum mean monthly temperature and minimum mean monthly temperature extracted from Climate Tool.

Firstly, the average of maximum monthly temperature and minimum monthly temperature of 12 months of every single year from 1960-2007 is calculated respectively. Secondly, the difference between maximum and minimum monthly temperature from 1960-2007 is calculated based on previous results. The final range of mean monthly temperature is the average value of the Second step.

In addition to the above climate data, HDM-4 deterioration model also requires the number of days greater than 32 ℃, the duration of dry season, and the percentage of time driven on water covered roads. These data are not provided by Climate Tool. By applying the extreme input data on these items, one can observe that these inputs have very minor effects on deterioration rate. Therefore, a default value of 90 days greater than 32 ℃, 6 months of dry season, and 5% of time driven on water covered roads are adopted for this study.

3. HDM-4 DETERIORATION MODELLING

The HDM-4 model predicts pavement deterioration as a function of pavement condition, traffic loading, environmental effects, and maintenance impacts. In this study, the modelling analysis is repeated for road sections with different traffic levels and various initial pavement conditions in South East Queensland (SEQ), therefore identifying the deterioration of pavements representing different level of road hierarchy. The pavement condition is expressed in terms of pavement strength. The traffic level is expressed in terms of the annual average daily traffic (AADT) and the composition of traffic.

3.1 Road Section Characteristics

A number of different flexible pavement road sections within the SEQ region have been selected for HDM-4 pavement deterioration modelling. There road sections are part of LTPP sites used by Queensland Department of Transport and Main Roads (QTMR) and Local City Councils for their own management purposes.

These chosen LTPP sites represents a range of typical road hierarchy including highway, arterial road and local road. They are defined by a unique set of location, age, geometric characteristics, environmental conditions, traffic loading, and pavement conditions respectively.

Four QTMR LTPP sites located in the Gold Coast and Brisbane have been chosen for pavement deterioration analysis as representatives of highway and arterial roads. In addition, twelve LTPP sites within Gold Coast, seventeen LTPP sites within Logan, fifteen LTPP sites within Ipswich, nine LTPP sites within Redland, eight LTPP sites within Caboolture, and seven LTPP sites within Caloundra have been selected as representatives of local roads throughout SEQ region. Part of the information of all of these LTPP sites collected from QTMR and corresponding local City Councils are summarized and shown from Table 1 to Table 4 below.

Table1: QTMR LTPP Sites

LTPP No.	Road Name	Block Length (m)
QTMP 1	Pacific Motorway, Southbound (Gold Coast)	500
QTMP 2	Samford Sub-Arterial Road (Brisbane)	250
QTMP 3	Moggill Sub-Arterial Road (Brisbane)	280
QTMP 4	Mount Cotton Road (Brisbane)	785

Table 2: Gold Coast City Council LTPP Sites

LTPP No.	Road Name	Block Length (m)
GCCC 1	Helensvale Road	346
GCCC 2	Johnston Road	270
GCCC 3	Dudgeon Drive	650
GCCC 4	Xanadu Court	435
GCCC 5	Shaws Pocket Road	1320
GCCC 6	Robina Parkway	1520
GCCC 7	Tallai Road	1214
GCCC 8	Lords Avenue	340
GCCC 9	Cheltenham Drive	941
GCCC 10	Studio Drive	860
GCCC 11	Tallebudgera Drive	386
GCCC 12	Larch Street	400

Table 3: Logan City Council LTPP Sites

LTPP No.	Road Name	Block Length(m)
LCC 1	Chambers Flat	439
LCC 2	Browns Plains	556
LCC 3	Middle	542
LCC 4	Station	674
LCC 5	Watland	522
LCC 6	Service	398
LCC 7	Passerine	580
LCC 8	Lawnton	417
LCC 9	Vansittar	470

LCC 10	Sports	320
LCC 11	Demeio	528
LCC 12	Crest	974
LCC 13	Muchow	446
LCC 14	Jalan	328
LCC 15	Federation	282
LCC 16	Conifer	458
LCC 17	Shailer	464

Table 4: Ipswich City Council LTPP Sites

LTPP No.	Road Name	Block Length(m)
ICC 1	Aster	253
ICC 2	Commercial	280
ICC 3	Salsibury	385
ICC 4	Briggs	298
ICC 5	Thagoona-Haigslea	295
ICC 6	Russells	300
ICC 7	Reif	400
ICC 8	Southern Amberley	350
ICC 9	Purga School	550
ICC 10	Augusta	410
ICC 11	Roland	605
ICC 12	Lawrie	255
ICC 13	Ash	304
ICC 14	Peak Crossing	250
ICC 15	Duncan	255

3.2 HDM-4 Data Input and Initial Model Set-up

3.2.1 Climate data input

For modelling any of the above LTPP sites, a series of climatic data are required as the input of HDM-4. They are obtained by using Austroads Climate Tool based on specific GPS locations and periods of time as described in previous sections of this chapter. The climatic inputs required by HDM-4 are listed as follows:

1. Thornthwaite Moisture Index (TMI)
2. Moisture classification & Temperature classification based on TMI
3. Duration of dry season in months
4. Mean monthly precipitation (MMP) in mm
5. Mean annual temperature (MAT) in ℃
6. Average monthly temperature range (MTR) in ℃
7. Number of days greater than 32 ℃
8. Freeze index (not applicable for SEQ)

3.2.2 Pavement structure and traffic data input

Input data is required to enable the definition of pavement structure. The data can be considered into two categories: pavement strength, and pavement configuration. Besides, several inputs represent the traffic composition must be taken into account. In this study, despite some of the data which can be obtained directly from QTMR and city councils without further process, some of them requires calculation base on proper equations or reasonable judgments. These procedures will be described in detail later this section.

3.2.3 Input for Pavement Strength

Pavement strength is a primary determinant of many pavement structural condition indicators. HDM-4 recognises this need through the use of the Adjusted Structural Number (SNP) as a modelled measure of pavement strength, but a means is required for the derivation of SNP from FWD deflection data [10].

The concept of Structural Number (SN) as a parameter for estimating pavement strength was developed from the American Association of State Highway and Transportation Official (AASHO) Road Test (Highway Research Board) for pavement design and performance purposes. Then SN parameter is based on the sum of each of the pavement layer strength coefficients [11] multiplied by its respective pavement layer thickness.

Modified Structural Number (SNC) is a modification of the SN parameter to include the subgrade contribution, SNsg, to pavement strength. The SNsg component estimates a negative contribution to pavement strength when the subgrade Californian Bearing Ratio (CBR) is less than 3%, and a positive contribution when it exceeds 3% and is therefore equal to the SN when the subgrade CBR is 3%. The SNC was used in the HDM-III to represent the pavement strength in predicting performance [12].

The SNC was further refined into the adjusted structural number, SNP, in the HDM-4 [13]. The parameter SNP uses a weighting factor [14] that reduces the contribution to pavement strength of the sub-base and subgrade with their increasing depth. This weighting factor was introduced because the strength contribution of each layer in the pavement system is independent of depth, with the SNC parameter resulting in over-estimates of SNC.

The SNP can be estimated from pavement surface deflection data measured by any of the following typical pavement surface deflection testing devices: Benkelman Beam (BB), Falling Weight Deflectometer (FWD), and Deflectograph (DEF). In HDM-4, pavement strength can be input as three different forms including:

1. FWD data
2. SN and CBR
3. BB deflection

Since pavement strength is described in terms of SNP in HDM-4, inputs on any of the above forms will be adjusted into SNP by the system.

In this study, FWD central deflection at an FWD load pressure of 700 Kpa is used for majority of the LTPP sites based on the available data. For those sites which do not have the FWD data, SN and CBR data are used for analysis.

3.2.4 Input for Pavement Condition (IRI)

The pavement condition is expressed in terms of International Roughness Index (IRI). As an input for HDM-4 deterioration modelling, the initial IRI are based on NAASRA roughness counts. This research referred to Yeaman's guideline[20] for pavement roughness which is shown in Table 5.

Table 5: Guideline for pavement roughness [20]

Type of pavement	Traffic	Roughness (NAASRA counts)
New construction	Arterial	< 50
New construction	Residential	< 60

These NAASRA counts were then converted into the IRI values by using the following equation:

$$NAASRA = 26.49 \times IRI - 1.27 \quad (1)$$

Where, NAASRA = Roughness level measured by NAASRA model (counts/km), IRI = International roughness index in m/km

The initial roughness for this study adopted a 50 NAASRA for arterial road and a 55 NAASRA for residential road. They are calculated into IRI value as 1.93 and 2.13 respectively.

3.2.5 Input for Traffic

3.2.5.1Vehicle fleet

The vehicle fleet is a list of vehicles that could be expected to be found on a road network. Various detailed vehicle operating information is required for each vehicle which effectively describe how the vehicle will behave and interact with the road [5]. In defining the vehicle fleet, four categories are used in the HDM-4 analysis. That is:

1. 3 axle vehicles (trucks and buses)
2. 6 axle vehicles (articulated trucks)
3. B-Double (road trains)
4. Passenger cars

Based on the fact that the number of heavy vehicles is the most critical since they contribute much more to pavement deterioration than passenger cars, the above categories could be further classified into two traffic types: heavy vehicles and passenger cars by combining the sum of 3 axle, 6axle and B-Double vehicles as heavy vehicle.

3.2.5.2 AADT

In HDM-4 the traffic flow pattern is represented in terms of the Average Annual Daily Traffic (AADT) which is defined as the amount or percentage of traffic expected over a certain amount of time per day. The collected AADT data involving multiple lanes were measured at approximately 10 to 20 year after the construction of the roads. For the purpose of this study, the AADT data need to be further processed based on the traffic growth rate and traffic lane distribution factor.

All of the chosen LTPP sites are located at the outer lane of a road section while the AADT data represent the total traffic of all lanes. Therefore, the AADT as an input of HDM-4 need to be distributed into the traffic volume over the outer lane according to the lane distribution factors. Table 6 shows the Lane Distribution Factor provided by Austroads [5] Pavement Design Guide. Within which, the left lane data is adopted as the outer lane traffic.

Table 6: Typical Lane Distribution Factors for carriageways [5]

Lane Distribution Factor (LDF)				
Location	Lanes each direction	Left lane	Centre lane	Right lane
Rural	2 lane	1.00*	N/A	0.5
	3 lane	0.95	0.65	0.30
Urban	2 lane	1.00*	N/A	0.5
	3 lane	0.65	0.65	0.5

*This value is the suggested limit for a lane and may be reduced

Moreover, the outer lane AADT have to be back calculated to the initial AADT which represents the traffic volume when the road section was first constructed. The initial AADT data are needed as the input for modeling the pavement deterioration of road sections from the first year after they were opened to traffic. As the collected traffic volume data are measured at some time after construction, traffic growth per year is required for the back calculation. The provided traffic growth data for different LTPP sites are tabulated as below:

Table 7: Traffic Growth Rate per year (%)

LTPP Site	M1	Moggill	Mt Cotton	Other local roads
Traffic Growth	8.5	3.9	5.3	3

3.3 Modelling of Roughness Progression

After definition of all the inputs for each pavement, a dynamic model system is established incorporating interaction between pavement strength, pavement condition, surface condition, traffic loading etc. This model predicts pavement performance over a continuous period of time in accordance with the many various inter-active influences.

The investigation of current pavement roughness progression is carried out based on the average current climate from 1960 to 2007. The prediction of future roughness progression is carried out based on three different periods between 2008 and 2099. As outlined in previous section, the future climate was projected for every 30 years in terms of the definition of climate and the typical pavement life cycle. However, when considering pavement performance and maintenance cost, the first 15 years of pavement life is the most crucial as it is the period before pavement condition deteriorates to fair condition. A focus on the first 15 years of pavement life cycle leads to reduced cost and extended using life of pavement [15].Therefore, the future pavement deterioration will be analysed for the first 15 years of every 30-year period, that is, from 2008 to 2025, 2041 to 2055, and 2071 to 2085.

4. CALIBRATION FOR LOCAL CONDITION

Due to the significant differences in traffic, economic, and environmental conditions during different time periods and between the specific regions, the HDM-4 model will be calibrated into the region where it is to be used to ensure the model represents the actual deterioration as accurate as possible. In this study, the calibration is carried out at level I for basic application [16]. The most sensitive factor in road deterioration, i.e. the K_{gm}, is to be calibrated for the chosen LTPP sites. The initial deterioration factors applied for current roughness progression modelling are based on the latest study for SEQ region conducted by CSIRO [18] and Chai et al [19], and shown in Table 8.

Table 8: Initial deterioration factors for SEQ [19]

Calibration	K_{ci}	K_{cp}	K_{rv}	K_{gm}	K_{pp}	K_{rp}	K_{gp}
	1.1	0.2	6.0	1.1	0.8	1.0	1.0

5. CURRENT CLIMATE ANALYSIS

Table 9 shows the current climate of SEQ in terms of Thornthwaite Moisture Index, annual rainfall, annual temperature, mean monthly maximum and mean monthly minimum temperatures. Corresponding graphs of current climate analysis are illustrated in Appendix A. This result was obtained based on the historical climate data between 1960 and 2007. According to the Thornthwaite Moisture Index classifications by Thornthwaite and HDM-4 [17], the historical climate study results indicate the current climate of SEQ belongs to humid.

Table 9: Summary of SEQ Climate (1960-2007)

	TMI	MAT (℃)	MMP (mm)	MTR (℃)
Gold Coast	52.30	20.08	112.5	9.75
Logan	44.60	20.07	107.85	8.17
Brisbane	63.20	20.06	127.10	9.54
Ipswich	62.37	19.89	124.95	9.84

6. FUTURE CLIMATE ANALYSIS

Table 10 to Table 13 demonstrate the summaries of future climate of the seven targeted locations during the period from 2008 to 2099 on 30-year increments. According to the above results, the values of future Thornthwaite Moisture Index of all the seven targeted locations indicate a decreasing trend in overall moisture conditions, meanwhile with a decreasing trend in mean monthly precipitation which could further confirm the decrease of Thornthwaite Moisture Index.

Once the current climate is identified and future climate is analysed, the general trend in climate changes over a long period of time can be determined. The future trends indicate a move from humid to drier sub-humid conditions within the next century. The trend in mean temperature is slowly increasing. This confirms the literature review findings of expected increases in temperature and decreases in precipitation for SEQ.

Table 10: Cold Coast Climate Summary

	TMI	MAT (℃)	MMP (mm)	MTR (℃)
Current (1960-2007)	52.3	20.08	112.5	9.75
Future Climate (2008-2040)	26.7	21.5	81.64	9.75
Future Climate (2041-2070)	14.9	22.5	57.5	9.75
Future Climate (2071-2099)	4.0	23.5	9.75	9.75

Table 11: Logan City Climate Summary

	TMI	MAT (℃)	MMP (mm)	MTR (℃)
Current (1960-2007)	44.60	20.7	107.85	8.17

Future Climate (2008-2040)	15.84	21.93	71.38	8.17
Future Climate (2041-2070)	7.21	23.39	50.94	8.17
Future Climate (2071-2099)	-1.16	24.79	31.80	8.17

Table 12: Ipswich City Climate Summary

	TMI	MAT (℃)	MMP (mm)	MTR (℃)
Current (1960-2007)	62.37	19.89	124.95	9.84
Future Climate (2008-2040)	41.07	21.13	93.84	9.84
Future Climate (2041-2070)	20.15	22.65	62.72	9.84
Future Climate (2071-2099)	-0.11	24.12	34.00	9.84

Table 13: Brisbane Climate Summary

	TMI	MAT (℃)	MMP (mm)	MTR (℃)
Current (1960-2007)	63.20	20.06	127.10	9.54
Future Climate (2008-2040)	51.20	21.27	102.36	9.54
Future Climate (2041-2070)	28.10	22.80	68.90	9.54
Future Climate (2071-2099)	6.40	24.20	37.53	9.54

7. FUTURE PAVEMENT DETERIORATION RATES

The second analysis conducted will examine future pavement deterioration rates due to climate changes and increases in traffic. The analysis is run three times under future climate periods up to the year 2099 by HDM-4 Modelling.

Table 14: Pacific Motorway deterioration

Year	2008-2040	2041-2070	2071-2099
1	0.67	0.67	0.67
2	0.74	0.74	0.74
3	0.84	0.84	0.83
4	0.89	0.88	0.88
5	0.94	0.93	0.92
6	0.99	0.98	0.97
7	1.05	1.03	1.03
8	1.12	1.09	1.08
9	1.18	1.15	1.14
10	1.25	1.22	1.2
11	1.32	1.28	1.26
12	1.39	1.34	1.33
13	1.47	1.41	1.39
14	1.55	1.48	1.46
15	1.63	1.55	1.53
16	1.71	1.63	1.6

Table 15: Mt Cotton sub-arterial road deterioration

Year	2008-2040	2041-2070	2071-2099
1	1	1	1
2	1.1	1.1	1.1
3	1.25	1.24	1.23
4	1.33	1.33	1.3
5	1.42	1.42	1.38
6	1.52	1.51	1.46
7	1.62	1.61	1.55
8	1.74	1.72	1.64
9	1.86	1.84	1.74
10	1.99	1.97	1.85
11	2.13	2.11	1.97
12	2.28	2.25	2.09
13	2.44	2.41	2.22
14	2.62	2.58	2.36
15	2.81	2.76	2.51

Table 14 and 15 show the trend of deterioration rates under combined climate changes and traffic increases up to year 2099 for selected LTPP sites. The role of traffic increases on deterioration rates is significant. For Pacific Motorway, the higher traffic volumes and high annual traffic growth lead to traffic dominating deterioration rates in the future. The effect of climate change can be seen later in the century as drier climate reduces deterioration rates; Mt Cotton sub-arterial road shows almost a balancing of increasing deterioration rates due to traffic and decreasing rates due to climate. It can be concluded that, while climate change does play a role in lower deterioration rates, traffic will have the most impact of future deterioration rates for higher trafficked roads.

8. CONCLUDING

There is an increasing body of evidence that the climate is changing and climate change can have impacts on road infrastructure due to the effects of the changed environment [5]. The primary objective of this project was to investigate the impacts of projected climate changes in the next

100 years of the South East Queensland region on flexible pavement performance. A number of preliminary works have been carried out according to the proposed research objectives. They are summarised as below:

1. Conducted a comprehensive literature review on climate change science with a specific focus on SEQ region, pavement performance modelling, effects of climatic factors on pavement performance and previous similar studies.
2. Extracted raw historical and projected future climate data by using Austroads Climate Tool. Calculated and interpreted extracted climate data into proper forms as the input of further study.
3. Collected data of targeted road pavement sections according to the requirement of the road pavement management analysis software – Highway Development and Management System (HDM-4).

Key findings of the climate data analysis at present include:

1. Precipitation and temperature are the major climatic factors affecting the pavement deterioration.
2. Analysis of the trends of climate change based on seven typical locations of South East Queensland indicates an average 1.1 ℃ increases in mean annual temperature from 2007 to 2040, 2.4 ℃ by 2070, and 3.7 ℃ by 2099.
3. Mean annual precipitation is projected to decrease by approximately 22% by 2040, 32% by 2070, and 42% by 2099.
4. Based on the HDM-4 calibration of LTPP sites, a relationship between Thornthwaite Moisture Index and average flexible pavement deterioration rates in IRI/year has been developed. This can be used for improving pavement performance prediction at a network level due to climate changes represented by changes in Thornthwaite Moisture Index.

Due to the uncertainty about future human behaviour and some aspects of climate science, precise predictions of climate change are uncertain and will remain so [5].To reduce uncertainty and improve confidence of future climate projections for the purpose of this study, effort is made by adopting a more reliable projection method.

This project has examined the effects of long term climate changes on pavement deterioration in SEQ and presents the results of the general trends expected. The findings suggest that decreasing rainfall (decreasing TMI) will slow flexible pavement deterioration. However, increases in temperature are likely to cause materials to expand; the bitumen binder to become more viscous; and deformation susceptibility to increase i.e. rutting. Solar radiation increases are likely to increase surface degradation through asphalt oxidation, embrittlement and cracking.

9. REFERENCES

[1] IPCC (intergovernmental Panel on Climate Change) (2007). Climate change 2007: contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, IPCC, Geneva.

[2] Garnaut, R. (2008). The Garnaut climate change review: final report, Cambridge University Press, Melbourne.

[3] Office of Economic and Statistical Research. (2010). Queensland Regional Profiles: SEQ Region, The State of Queensland, Queensland Treasury.

[4] Department of Infrastructure and Planning. (2009). South East Queensland Regional Plan 2009-2031, The State of Queensland.

[5] Austroad. (2004). Impact of climate change on road infrastructure, Austroad Inc.

[6] Carrera, A., Dawson, A. & Stegar, J. (2009). Report Nr 1 – State of the art of likely effect of climate on current roads, ERA-NET ROAD

[7] McDonald, J., Baum, S., Crick, F., Czarnecki, J., Filed, G., Low Choy, D., Mustelin, J., Sano, M. & Serrao-Neumann, S. (2010). Climate change adaptation in South East Queensland human settlements: Issues and context, unpublished report for the South East Queensland Climate Adaptation Research Initiative, Griffith University.

[8] Austroads. (2010). Impact of climate change on road performance: updating climate information for Australia. Austroads Incorporated, Sydney.

[9] Walsh, K., Cai, W., Hennessy, K., Jones, R., Mclnnes, K., Nguyen., Page, C. and Whetton, P. (2002). Climate Change in Queensland under Enhanced Greenhouse Conditions, CSIRO.

[10] Loizos, A., Roberts, J. & Crank, S. (2002). Asphalt pavement deterioration models for mild climatic conditions. Ninth International Conference on Asphalt Pavements. Copenhagen, Denmark.

[11] AASHO. (1972). AASHO interim guide for design of pavement structures, American Association of State Highway Officials, Washington DC, USA.

[12] Watanatada, T., Harral, C. G., Paterson, W. D. O., Dhareshwar, A. M., Bhandari, A. &

Tsunokawa, K. (1987). The highway design and maintenance standards model: volume 1: description of the HDM-III model, John Hopkins University Press, Baltimore, USA.
[13] Morosuik, G., Riley, M. & Odoki, J. B. (2001). HDM-4 modelling road deterioration and works effects: review draft version 1.1: vol. 6, World Road Association (PIARC), Paris, France and the World Bank, Washington DC, USA.
[14] Parkman, C. C. & Rolt, J. (1997). Characterisation of pavement strength in HDM-III and possible changes for HDM-4, Transport Research Laboratory (TRL), unpublished report, PR/ORC/587/97, TRL, Crowthorne, Berkshire, UK.
[15] Akyildiz, S. (2008). Development of new network-level optimization model for Salem district pavement maintenance programming. Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia.
[16] Bennett, C. R. & Paterson, W. D. O. (2002). A guide to calibration and adaptation. Volume V, HDM-4 Manual. World Road Association, ISOHDM, PIARC, Paris, France.
[17] Odoki, J. B. & Kerali, H. G. R. (2000). Analytical framework & model descriptions, Highway development and management series volume 1 part C, World Road Association (PIARC), Paris, France.
[18] CSIRO (Commonwealth Scientific and Industrial Research Organisation) & BoM. (2007). Climate change in Australia: technical report 2007, CSIRO, Melbourne.
[19] Chai, G. W., Chowdhury, S. H., Kelly, G., Bartlett, R. & Loo, Y. C. (2010). Establishment of calibration factors for pavement roughness deterioration model in southeast Queensland. Australian Journal of Civil Engineering, Vol 8, No 1.
[20] Yeaman, J. (2002). A study guide for pavement maintenance & rehabilitation, Centre for Pavement Engineering Education, Deakin University.