Selection of performance grade asphalt binders cements environmental sciences ess...

The details of the investments on roads were obtained through the working group papers of the 12th five year plan which have been classified as central roads (National Highways, State highways etc), Urban roads and Rural roads (only Pradhan Mantri Gram Sadak Yojana has been included in this). The total investment on all is about Rs. 2, 62, 850 crores. The breakdown of this can be seen in Table 4. 1. For central roads and urban roads these have been further classified. The central roads have various projects like the National Highways Development Project, Special Accelerated Road Development Programme in North East, Special Programme for Development of Roads in the Left Wing Extremism (LWE) Affected areas etc. All these projects have separate estimates of costs of construction. In the urban areas, investments on roads and the costs of construction have been estimated separately for different classification like mega cities, other metros, cities with population of 5-10 lakhs and cities with less that 5 lakhs population. Table 4. Investments on New Roads in the 12th Five Year PlanCategoryKilometresInvestment (Rs.) (Crores)Central Roads35, 2481, 21, 242Urban Roads33, 99285, 984Rural Roads (PMSGY)2, 56, 42555, 624Total3, 24, 7652, 62, 850Source: (Planning Commission 2011; 2012)Note: Refer Appendix I for more detailed break upThe total costs of construction were divided by the number of kilometres proposed for each project/programme and the unit cost of construction was arrived at. The dose response values were applied to these to come up with the change in costs of construction per kilometre and then added up to come up with change in total cost of construction. Table 4. 2 shows the indicative estimates for the change in the costs of construction. This basically shows us that change in costs of construction if roads are constructed with specific design code updates which would make them more resilient to the change in climate variables during their lifespan. The total change in construction costs therefore come to 2855. 28 crores ($ 520 million approx) which is about 1. 08 per cent of the total investments on roads in the 12th five year plan. Table 4. Change in Costs of Construction due to building code updatesCategoryAdditional costs of construction (Rs.) (Crores)Percentage of total investment (%)Central Roads1321. 541. 09Urban Roads926. 331. 09Rural Roads607. 591. 09Total Change in Costs of construction2855. 541. 09Source: Authors Estimates[1]Table 4. 3 shows the indicative estimates of maintenance cost over the lifespan of the roads. This increase in costs would be required if the building codes and standards are not updated. In the EACC study it is assumed that all infrastructures constructed after 2010 would be constructed with updated codes and thus there would be no increase in maintenance costs for them. Table 4. Increase in maintenance costs due to climate change impactsCategoryAdditional costs of Maintenance (Rs.) (Crores)Percentage of total investment in construction of new roads (%)Central Roads6195. 215. 23Urban Roads1515. 031. 76Rural Roads18072. 7832. 49Total Change in Costs of maintenance25783. 029. 99Source: Author’s estimates17It can be seen that in comparison to construction costs, maintenance costs over the lifetime of the roads constitute a higher percentage of the investments on construction of new roads. This cost is for the lifespan of the roads which and even then comes to just about $ 4. 7 billion dollars for the new roads planned in the 12th five year plan. The figures above suggest that adaptation costs for the extensive network of roads planned in India would not be of much consequence as the costs for it would mean spending $ 520 million additional expenditure through updating of codes of construction right now or an additional expense on maintenance of $4. 7 billion dollars throughout the lifespan of the road which would come to approximately $ 2. 4 million dollars on an average per year. This is comparable to the results of the EACC study which says that the total costs of adaptation for infrastructure is less than one per cent of the baseline costs according to this study. The next chapter looks at some regional and country studies on impacts of climate change on roads and costs of adaptation. It is important to understand the impacts of climate change on each infrastructure type for a better estimation of costs of infrastructure adaptation. In the section above, the methodology of the EACC study, essentially the dose response method was applied to get an approximate estimate of the costs of adaptation for roads in the 12th five year plan. However, the technique seems to be to simplistic in the view of the complex nature of the impacts of climate change and the uncertainty around the impacts. There has been no in depth study on roads and adaptation options for roads, but a general method applied for all infrastructure types. It is important to understand the impacts of climate change on roads to plan the best means of adaptation to avoid or reduce these impacts. Below is the review of three regional/country studies below which try to understand the impacts of climate change or estimate costs of adaptation for roads. Study on Impacts of Climate Change on Pavement Infrastructure in Southern CanadaThis study (Mills, et al. 2007) was carried out in two parts to examine the generalized impacts of climate change on roads in greater detail. In the first set there is a detailed investigation into the climate indicators associated with pavement deterioration that are routinely applied in pavement management systems. This is done on seventeen sites. The second set of studies was done by applying the Mechanistic Empirical Pavement Design Guide (MEPDG) on six sites in order to evaluate the impact of pavement structure, material characteristics, traffic loads and change in climate on in incremental and terminal pavement deterioration and performance. Extensive literature review is done to understand the pavement management practices in Canada, measures of pavement performance, life cycle cost analysis (LCCA) of pavements, impacts of climate and weather on pavement performance and deterioration and potential impacts of climate change on pavements. The climate indicators chosen for the study were; Extreme minimum daily temperature; 7-day average maximum daily temperature; Freezing and thawing indices. The first two indicators contribute to thermal cracking and rutting respectively and are used in the selection of appropriate asphalt binders. Freezing and thawing indices are useful to understand the freeze/thaw depths, pavement strength and particularly to manage traffic loads. ((Mills, et al. 2007)17 sites were chosen on the basis of location (southern Canada), proximity to test section in the Long Term Pavement Performance (LTTP) program (more relevant for MEPDG analyses) and availability of daily temperature records. Table 5. 1 gives the names and the temperature and precipitation details of the 17 sites. Collectively the Census Metropolitan Areas (CMAs) or Census Agglomerations (CAs) represented by these sites consisted of over 53 per cent of the Canadian population and covered a wide range of environmental conditions experienced in southern Canada. Figure 5. 1 shows the steps in analysis of the climate change impacts. Table 5. Case study sitesCityMean Annual Temperature (ºC)Mean Annual Precipitation (mm)Vancouver10. 11199. 0Kelowna7. 7380. 5Calgary4. 1412. 6Edmonton2. 4482. 7Regina2.

8388. 1Winnipeg2. 6513. 7Thunder Bay2. 5711. 6North Bay3. 81007. 7Muskoka4. 91098. 6Windsor9. 4918. 3Toronto7. 5792. 7Ottawa6. 0943. 5Montreal6. 3978. 9Quebec4. 01207. 7Fredricton5. 31143. 3Halifax6. 31452. 2St. John’s4. 71513. 7Source (Mills, et al. 2007)Source: (Mills, et al. 2007)Baseline time series of daily minimum, maximum and mean temperature and total precipitation data for the years 1951-2001 were used. Two climate change scenarios were adopted for the purposed of this study; one was the A2x emission experiment from the Canadian Centre for Climate Modelling and Analysis Coupled Global Climate Model 2(CGCM2A2x) and the second the B21 experiment through the Hadley Climate Model 3 (HadCM3B21). The outputs from these models were downscaled by two methods. One is by adjusting the historic time series by an average change factor derived for an output for a particular cell in the model. The second was using LARS-WG, a stochastic weather generator developed by Semetove et all (as cited in Mills, et al. 2007). 3 random, synthetic, 50 year daily time series was produced for the baseline and each climate scenario. This data was then used to calculate baseline summary stattistic for each of the pavement deterioration relevant indicator. These have been discussed below.

Selection of Performance Grade Asphalt Binders/Cements

The selection of suitable performance grade (PG) asphalt binders or asphalt cements (PGAC) is done using the extreme minimum daily temperature and 7-day average maximum daily temperature as indicators. " A suitable PGAC will minimise thermal cracking under cold temperatures while simultaneously minimising traffic-induced rutting under hot temperatures" (Mills, et al.

2007). There are ratings for the asphalt binders/cements which have been arrived at after extensive laboratory material testing. An example of this is PG 58-28 which implies that the asphalt cement can minimise thermal cracking till a minimum daily surface pavement temperature of -28ºC and traffic-induced rutting till a 7 day maximum pavement temperature of 58ºC with a 98% reliability over its lifetime. The pavement temperatures were calculated using Superpave formulae developed in the LTTP program and from the Road Weather Information System (RWIS) data from Ontario. The results of the analysis are given below. In all of the 17 sites there is expected to be an increase in the daily minimum and 7-day mean maximum temperature. The daily data is used to extract annual extreme minimum daily temperature and annual extreme 7-day maximum mean temperature for each year of the simulation. These were then applied to the Superpave and RWIS based pavement temperature formula to estimate required PG ratings. The results suggested that there for low temperature thresholds would be no change in PG ratings at any of the sites under the HadCM3B21 scenario while 7 out 17 sites warmed up by one category under the CGCM2A2x scenario for both Superpave and RWIS based approaches. With the exception of one site (Edmonton), the baseline thresholds were similar for both the approaches though the specific sites with changed PG ratings were not the same for the two algorithms. Results for the baseline maximum PG temperature thresholds suggest that for the Superpave algorithms these the ranged between 52ºC (Vancouver, Calgary, Edmonton, North Bay, Halifax and St. John’s) to 58ºC (Kelowna, Regina, Winnipeg, Thunder Bay, Windsor, Muskoka, Toronto, Montreal and Fredricton) while for the RWIS based algorithms these ranged between 46ºC (Vancouver, North Bay, Halifax and St John's) to 58ºC (Kelowna, Regina, Windsor). On applying the climate change scenarios the upper limit of these went up to 64ºC(Kelowna, Windsor) and 70ºC (Kelowna) for the Superpave and RWIS algorithms respectively For the Superpave algorithms, there was and increase of PG ratings by one category in 6 of the 17 sites under the HadCM3B21 scenario and 4 out or 17 in the CGCM2A2x scenario. For the RWIS algorithm, the PG ratings increased for 13 of the sites under the HadCM3B21 scenario and in 11 of the sites under the CGCM3A2x scenario.

Freezing and Thawing Indices

Freezing and thawing indices are used to calculate spring load restrictions (SLR)[2]and winter weight premiums (WWP)[3]in Canada . Freezing index(FI) calculations begin in the months of October to May after the first day that the mean daily temperature falls below 0ºC. º below zero are added and above zero are subtracted each day and accrued until the threshold level is reached and sustained for 7 days a surrogate for frost penetration to a depth of approximately 40 cm to increase the pavement. Once a site reached the critical FI a daily thawing index (TI) is calculated for each day when the daily mean temperature exceeded -2ºC which corresponds to a temperature of 0ºC at the base of the asphalt layer. SLRs are required to mitigate pavement damage when cumulative daily TI reaches and sustains a critical value. The recommended SLR day is estimated by considering of the attainment of at least 30 º days with seven days and an average TI of 21. 5 º days. The freeze-thaw analyses basically consisted of comparing the timing of critical FI, critical TI and the length of the freeze season (sum of days between FI and TI) for baseline and climate change scenarios. The baseline median duration to reach critical FI ranged from 58 days to 116 days and the same to reach critical TI ranged from 131 to 187 days. The days to reach critical FI increased and the days to reach critical TI decreased under the climate change scenarios. Under the CGCM2A2x scenarios, 50 per cent of all seasons fail to reach critical FI (and thus critical TI also) in 5 (Kelowna, Windsor, Vancouver, Toronto and St. Johns) sites and among the rest of the sites the median duration of days required to reach critical FI increase in range of 4 (North Bay) to 27 days (Halifax). The days to reach critical TI range from 10 (Thunder Bay) to 31 days (Muskoka). Under the HadCM3B21 scenario, critical FI is achieved in at least 50 per cent of all season at all sites except Vancouver. The median values for most sites increases by one to two weeks except for five sites (Kelowna, Toronto, Windsor, Halifax and St. John's) where the median is increased by 28 days. In all sites except Kelowna, Critical TI is achieved earlier in the season with the median duration ranging from 2 to 14. 5 days earlier than baseline. As Kelowna, median values increase by 3 days. The baseline values for the mean duration of the freeze season ranged from 0 days in Vancouver to 122 days in Winnipeg while the baseline standard deviation for most sites ranged from 15-20 days for most sites except Vancouver which had no freeze season and Calgary and Edmonton where there was greater variability. There was a substantial drop in the mean duration of the freeze season from 8 per cent at Winnipeg (HadCM3B21) to 98 per cent at St John's and Windsor sites (CGCM2A2x). The CGCM2A2x scenario produced more reductions in the season lengths.

Application of Mechanistic-Empirical Pavement Design Guide (MPEDG)

This set of case studies were done to assess how a combination of environmental factors along with pavement structure, traffic, maintenance etc. would affect the deterioration and performance of the selected pavement sections over time in terms of International Roughness Index(IRI), cracking and pavement deformation or rutting. The Mechanistic-Empirical Pavement Design Guide (MPEDG) and software was used to conduct these case studies at 6 of the 17 earlier sites which are part of the Long Term Pavement Performance (LTPP). The LTPP database was used to extract baseline traffic, pavement structure and pavement material characteristics. A design life of 20 years was chosen for the analysis of pavement performance in all the applications of MEPDG. The profiling of the selected test sites were done and these represent a range of pavement structures and materials found in Canada. Some of these are shown in table 5. 2Table 5. Case study site characteristicsSource: (Mills, et al. 2007)MEPDG was applied in the test sites to assess changes in pavement performance and to understand the separate and combined effects of climate, climate change, traffic growth and pavement structure. Table 5. 3 shows the analysis parameters used for this study. Table 5. Analysis parameters used in MEPDG (Design life of 20 years)Analysis ParameterThreshold/LimitInternational Roughness Index (IRI)[4](m. 8/km)2. 7AC longitudinal cracking (m/km)378. 8AC Alligator crackin (% surface coverage)25. 0AC transverse crackin (m/km)189. 4AC deformation (mm)6. 4Total Deformation (mm)[5]19. 1Source: (Mills, et al. 2007)Results. It is suggested by the results of the six case studies that terminal pavement deterioration is sensitive to climate change. The most significant increase from the baseline climate was for AC rutting which was in the range of 14 to 36 per cent increase across sites. Alligator cracking also increases across all sites from 2 to 14 per cent. Logitudinal cracking increased at all sites in the range of 0 to 9 per cent except in Quebec and British Columbia where there was a slight decrease of 0 to 2 per cent. There was a less than 3 per cent difference between climate change scenarios for transverse cracking. Very small change (-1 to 2 per cent) were observed to terminal IRI values between the baseline and climate change scenarios. For most of the sites there was reduction in the time taken to reach the threshold limits for longitudinal cracking, alligator cracking, IRI and AC rutting and an increase in the time take to reach total rutting and transverse cracking limits. TA 4 per cent per annum growth scenario was applied in the second part of the study with the baseline climate and climate change scenario. This increased the absolute pavement deterioration along with shorter timespan to achieve the maintenance related thresholds. But the relative impacts of climate change with an increasing traffic scenario as compared with that of no growth is found to be similar (less than 3 per cent)

Conclusion

The study states that the pavement management systems of Canada are carefully engineered and adaptive. It also says that the impacts of climate change suggested in this study fall within the range of conditions currently experienced in North America. Thus the main adaptation issue of the road authorities in Canada would be the timing of implementation of current design and maintenance practices. But also the fact that more significant impacts associated with climate change may be felt in the secondary and tertiary networks of provincial and municipal agencies due to the combination of weak pavement structure along with heavy traffic loads. The study on the climate proofing of EU policies (Altvater, et al. 2012) looks at various options to address the impacts of climate change in different sectors and does an assessment of these options. It studies at different policies s in four sectors; energy, transport infrastructure, urban areas and agriculture. Key policies are screened for how adaptation has been addressed and what are the gaps i. e. the climate change threats that are not specifically considered or addressed. This is followed by an analysis of adaptation and policy options for each sub sector. This leads to suggestions on which policy options can be considered for an assessment of costs. The assessment of costs is done through a variety of methods which involves literature reviews of bottom up studies of costs of adaptation, extraction of cost information from various sources including expert interviews. In the transport infrastructure sector, various existing policies of European Union (EU) related to infrastructure and policies are assessed for how the climatic risks have been addressed in them. According to the gap analysis, " most existing transport policies (cf. I), do not explicitly address the climatic pressures (e. g. increase of temperature) and impacts which can be expected in the future as potentially harming transport infrastructure." (Altvater, et al. 2012) This study states that a " multiple-benefits[6], no-regret and low-regret" adaptation options should be favoured in the transport infrastructure sector. Next, this study discusses the various impacts of climate change on roads which would result from high temperatures, extreme precipitation/floods, sea level rise and permafrost degradation. This is shown in Table 5. 4. Table 5. Impacts of climate change on road infrastructure in the European

UnionConsideredpartClimaticpressuresRiskTime frame ofexpectedimpactArea mainlyAffectedRoads(including otherinfrastructuresuch asbridges, tunnels etc.)Summer heatPavement deterioration and subsidence; melting tarmac; reduced life of asphalt road surfaces (e. g. surface cracks); increase wildfires can damage infrastructure; expansion /buckling of bridgesMedium negative (2025; 2080) to high negative (2080)SouthernEurope(2025), West, East andCentral EU(2080)Extremeprecipitation/floodsDamage on infrastructure (e. g. pavements, road washout); road submersion; scour to structures; underpass flooding; overstrain drainage systems; risk of landslides; instability of embankmentsMedium negative (2025) to high negative (2080)EuropeanWideExtreme stormeventsDamage on infrastructure; roadside trees/vegetation can block roads In general: speed reduction; road closure or road safety hazards; disruption of " just in time" delivery of goods; welfare losses; higher reparation and maintenance costsNo informationNo informationCoastal roadsSea level riseDamage infrastructure due to flooding; coastal erosion; road closureMedium negative (2080)EuropeanWideExtreme stormEventsNo informationNo informationHeavyprecipitationeventsMedium negative (2025) to high negative (2080)EuropeanWideMountain roadPermafrostdegradationDecrease of stability; landslides; road closureNo informationNo informationSource: (Altvater, et al. 2012)The then goes on to look at what could be the possible options for adaptation and the assessment of costs. The adaptation options consists of - (a) Technical Measures; (b) Regulations and Standards; (c) Capacity Building ; (d) Communications and Awareness; (e) Guidelines and (f) EU Financing schemes. The next step was looking at how much would it cost to retrofitting the roads for higher temperatures and precipitation. The costs include costs of construction, additional maintenance and renewal. The report states that higher temperature would mainly lead to rutting of road and the use of heat resistant asphalt would be enough to adapt to the impacts of climate change. Asphalt consists of 95% aggregates (crushed rock, sand, gravel or slags) and 5% bitumen as binder material. The average unit prices were not available for conventional asphalt, or high temperature resistant asphalt or highly sophisticated asphalt. Therefore it was not possible to arrive at a price per km road. Thus the estimates are based on costs per kilometre for motorway renewal in Canton, Zurcih which is about € 1. 75 million . For the renewal prices of other roads the study has referred to an average of costs in Switzerland for state (72, 000 Swiss Franc/km) and national roads (417, 000 Swiss Franc/km). For better asphalt, the values of 5-15% additional costs have been used and renewal cycles for motorways was 15 years while for other roads it was 10 years.. For effect of precipitation on roads, the study considers at increasing the drainage capacity as the most appropriate method of adaptation and costs were calculated for 100%, 50% and 25% increase of drainage capacity. The additional costs for a better surface asphalt for the European Union is given between € 2973 million to € 8918 millions which comes to about 5 to 15 per cent of the original (baseline) costs. In addition to these are the costs for increasing drainage capacity which would be long term investments. These costs range are € 48. 64 , 121. 16 and 243. 22 millions for increasing drainage capacity by 25%, 50% and 100% respectively. So the total costs would be much higher that would have been estimated by the dose response values which basically talks about 1. 07 per cent increase. Another study which takes a different approach to estimation of costs of adaptation for roads is done by Austroads Inc (2004). This was a joint project funded by Austroads and the Commonwealth Department of Transport and Regional Services. This study provides an assessment of the likely impacts of climate change for Australia for the next 100 years on the patterns of demography and industry. This information is used to predict the demand for road infrastructure and the likely effects on the existing road infrastructure. The study also identifies the potential adaptation options in road construction and maintenance and finally reports on the implications for policy from the results of the projects. The climate change projections were done by CSIRO using the A2 emissions scenario in it atmospheric-ocean global climate model (AOGCM). The results were used to ‘ nudge’ the Conformal-Cubic General Circulation Model (GCM) of the CSIRO to give high resolution over Australia. The results were monthly means of average, maximum and minimum temperatures, solar radiation and potential and actual evaporation for each grid point of 50 square kilometres. It was estimated that the average annual temperatures would increase by 2 to 6 º Celsius by 2100 which will not be uniform with places like Tasmania and the coastal belts being the least affected and the inland areas the most affected. Most models predict a rainfall decrease but northern areas are seen to have extensive areas of rainfall increase in some models. The factors shaping Australia’s population and pattern of settlements were studied by the Monash University Centre for Population and Urban Research. These are fertility, mortality and international and internal migration. Projections for population for the whole of Australia, different states and eight major metro cities were developed. The impacts of the forecasted climate change were reflected through adjustments which were based on ‘ expert’ judgment and supported by the relative strain index or comfort index[7]. It is assumed that the total fertility rate will fall to 1. 6 and the net overseas migration would be 90, 000 per year over the 21st century. The total population is projected to grow from from 19. 1 million in 2000 to 27. 3 million in 2100. The trends of industrial restructuring would strongly favour concentration of populations in the metropolitan cities. Table 4. 1 shows the change in population from 2000 and adjustments to account for climate change. Table 5. Adjustment in population due to climate changeSelected Statistical Division2100 population as a percentage of 2000 population (without climate change)2100 year population adjustment factor (with climate change)Climate change factors driving the population changeSydney159%1. 00Higher temperature but not expected affect population growthMelbourne125%1. 15Higher temperature make climate more attractiveBrisbane211%0. 96High temperatures make climate less attractiveMoreton205%0. 98High temperatures make climate less attractiveAdelaide63%0. 79Restricted water supply particularly in springPerth195%0. 88Less attractive climate and restricted water supplyDarwin175%1. 34High temperatures but heavy rainfall drives agricultureACT93%1. 00High temperatures but does not affect population growthCairns278%0. 83High temperature makes climate less attractiveSource (Austroads 2004)As a result of climate change, Darwin and Melbourne would gain more population while the population of Sydney and ACT are not likely to be affected. The results suggest that the areas which would gain population as a result of climate change are New South Wales, Victorian Coastal Regions and the northern part of the Northern Territory. Perth, Adelaide, Queensland and inland southern and central Australia in general are expected to lose population. The impact of climate-adjusted population on demand for road use was studied by ARRB Transport Research. For this both passenger and freight transports have to be considered and the climate adjusted population distributions were used as a key driver of transport demand. The modified population projections were used to generate a set of " Origin-Destination" population factors which were used for travel demand analysis. The following equations were used for this purpose:

Equation 1

Future Passenger Car Travel = Baseline AADT[8]* (1-%HV) * Population Factor * Cars per CapitaFor the freight transport task, a similar approach was used as illustrated in Equations 2 and 3.

Equation 2

Future Heavy Vehicle Travel = Baseline AADT * %HV[9]* Population Multiplier * Freight per Capita Factor / Payload Factor

Equation 3

Future Heavy Vehicle Average ESAs[10]= Baseline Avg ESAs * ESA Factor(Austroads 2004)An extensive study of the change in the road use demand was done and also various issues such as car ownership make up of vehicle fleet and axle mass limits were considered. The results generalised across the National Highways are: A 60 per cent increase in total traffic including both passenger and freight. The increase in demand will be very high in Queensland, moderate in Melbourne – Sydney corridor. It will decline near Adelaide. The urban traffic in Perth would increase. The proportion of heavy freight vehicles will increase from 12. 1 to 13. 9%There would be an increase of 112 per cent in the total amount of road freight carried from 2000 to 2100An increase of 25 per cent in the average freight payload from 2000 to 2100. The average ESA per articulated truck will double due to higher axle mass limitsA combination of freight growth, increased mass limits and higher ratio of ESA payload will lead to an increase in the total ESA-kms on the National Highway by 230 per cent. The impact of climate change and the change in road use demand on pavement performance was studied next. The " Thornthwaite Moisture Index" was used to represent climate. It is a function of precipitation, temperature and potential evapotranspiration. The deterioration of roads with a higher value of the Thornthwaite Index will happen at a higher rate that those with a lower value for the same traffic loading. This is because moisture affects the structural performance of the pavement while temperature affects surface performance due to bitumen aging effects like oxidation (Austroads 2004). Two approaches were used for the pavement modeling in order to come up with the impacts on road infrastructure; (i) ARRB Transport Research pavement life cycle costing (PLCC) model and (ii) Highway Development and Management 4(HDM4) model. The PLCC model uses the roughness predictions for a set of defined roads categories to estimate the life cycle road agency costs and road user costs. The road agency costs consists of maintenance and rehabilitation costs while the road-user costs include travel time and vehicle operations. This is calculated as the present value of both the costs combined for a 60 year analysis period with a discount rate of 7 per cent. Treatment options and timings are also selected by the model in order to minimize the present value of costs. This is subject to the specified constraints on maximum roughness or annual agency budget limits. In PLCC, roughness is a function of pavement age, cumulative ESAs, the Thornthwaite index and annual average maintenance expenditure (proxy for agency maintenance treatments. The entire National Highway network was split into 60 different road sections, each having similar characteristics of climate, traffic levels, vehicle mix and pavement type. A HDM4 analysis was carried out for eight selected road segments (one from each state and territory) under the same climate change and transport demand scenarios as in PLCC model. The pavement deterioration algorithms are more details in HDM4 which uses a set of interdependent algorithms which cove rutting, roughness, cracking, potholing, etc and thus has more detailed data requirements. Site-specific predicted changes in Thornthwaite index, AADT and per cent heavy vehicles were used in the model. The roads user cost estimated by the PLCC model was $ 22, 247 million in 2100 as compared to $11, 660 in 2000. The results of the PLCC model show varied results within Australia for road agency costs. Table 5. 6 displays the summary of the road agency costs across the different states. Table 5. Summary of Road Agency CostsStateAnnual Agency Costs ($ million)ChangeBaselineNewNew South Wales72. 390. 125%Victoria3237. 618%Queensland82124. 251%Western Australia48. 356. 116%Southern Australia27. 623. 4-15%Tasmania6. 56. 85%Northern Territory17. 937. 3108%Australian Capital Territory0. 60. 717%Total287. 3376. 131%Source: (Austroads 2004)It can be seen that the change in road agency cost varies from -15% in Southern Australia to 108% in Northern Territory. Nationally it can be seen that the costs go up by 31%. The decline in the costs in Southern Australia may reflect the " combination of a drier climate and the effects of a relative reduction in population and associated lower traffic levels" (Austroads 2004). Northern Territory and

Queensland have higher costs due to increase in population and a generally wetter climate that has been forecasted in 210.

DISCUSSION AND CONCLUSION

The World Bank (2010) estimates for costs of adaptation for infrastructure come at the middle range of the UNFCCC (2007) study. The lower end of the World Bank estimate is pushed up because of a more detailed coverage of infrastructure and also due looking at different types if infrastructure to differentiate costs and risk. The World Bank estimates are pushed down because adaptation is measures against a consistently projected development baseline and a smaller multiplier is used on baseline investments (World Bank 2010). This has been stated in the report itself. The very low values of dose- response that have been used for the effects of change in climate stress on costs of construction and maintenance have to be analysed. The EACC study had done extensive modelling to come up with projection equations for an efficient level of infrastructure. The efficient level of infrastructure is defined as" that which would be reached if the country had invested up to the point at which the marginal benefits of additional infrastructure just cover the marginal costs—both capital and maintenance—of increasing the stock of infrastructure."((Hughes, Chinowsky and Strzepek 2010). This approach tries to remove the factor of underinvestment in infrastructure in developing countries (AICD, 2009). The study argues that it is a development issue that is separate and not directly associated with climate change. But how is it possible to adapt to climate change without adequate development in a country? Also in the context of climate change, adaptation and development need to go hand in hand. It is also argued that the adaptation deficit in developing countries is largely a development deficit (Parry, et al. 2009). Thus the two cannot be separated. Schipper (2007) has discussed the adaptation approach, which is largely favoured by multilateral and bilateral organisations like Work Bank, and vulnerability approach to adaptation. This comes down to basically accounting for climate change in social, institutional and development planning. But the existing development trajectories themselves contribute to increasing vulnerability and are not synchronised to the objectives of adaptation (Schippper, 2007). Then this approach taken by the World Bank in estimation of adaptation costs ignoring the fact that adaptation is a process and not just an outcome. Secondly, the dose response values have been calculated based on existing building code guidelines in the United States. The references for building code updates have been from a promotional literature on implementation of seismic code updates across cities in the United States (FEMA 1999) and thus it basically talks about how less is the incremental costs involved in updating the building code. This may not be the same for developing countries. The kind of construction practices that exist in the United States in terms of better technology and efficiency may not be comparable to the existing situation in most developing countries. The quality of existing infrastructure, the type of construction practices and existing design standards may be a great factor while comparing across the developing countries in order to come up with better dose response values applicable to each country or at least regions/classifications. These should be based on bottom up approach through studies conducted in developing countries on implementation of building codes, effect of change in climate variables on the condition of infrastructure. Another important aspect which has not been considered for estimation of costs of adaptation for infrastructure is the costs of impacts that cannot be avoided even after adaptation i. e. cost of residual damages. The costs of adaptation have been defined as the costs of " development initiatives needed to restore welfare to levels prevailing before climate change" and not for " optimal" levels of adaptation (World Bank 2010). In addition, in the case of costs of adaptation for roads, there are some studies on the impacts of climate change on roads and costs of adaptation which use different methodologies to arrive at their estimates. It would make sense to understand these studies and look at their methodologies and limitations. This would help to come up with more effective methodologies and robust models to predict the costs of adaptation. It can be seen that these studies (Austroads 2004; Altvater, et al. 2012; Mills, et al. 2007) take a more bottom up approach and some use pavement deterioration and life cycle analysis models (HDM4, PLCC, MEPDG etc) to come up with more realistic results catering to local conditions.

WAY FORWARD

It is necessary that such studies be undertaken in developing and least developed countries for different infrastructure types considering the fact that they are the most vulnerable to the impacts of climate change not only geographically but in terms of the development/adaptation deficit. This would provide a more realistic and practical input not only to national level policy makers but also to the international community to understand the funding and more importantly the technology transfer requirements . Also there needs to be a knowledge network between at least the developing countries so that such studies are shared and there is a better understanding of adaptation practices and costs in order to make effective adaptation strategies . In conclusions, adaptation to climate change is a critical issue that cannot be ignored. It is important even more in the context of infrastructure as it provides the basic thrust for the economy and protects lives, property and enhances the quality of living. There are challenges to adaptation in this sector related to risk and uncertainty which are inherent in any climate change projections and climate change models. Therefore while evaluating adaptation options it is important to have at least a preliminary understanding of the various costs and benefits involved in a particular path of adaptation. Thus the assessment of costs and benefits are integral for any planned adaptation which has to be done in the infrastructure sector, more so because of the high capital costs and sunk cost which are involved in large scale infrastructure development. There is also a lack of research done on the benefits of infrastructure adaptation which makes it difficult to have an economic assessment and most of the existing research is related to financial flows. The integrated assessment models do not come up with sectoral estimates and mostly look at all sectors or market and non market sectors. Furthermore there is a need to consider the infrastructure deficit and the institutional governance for addressing this deficit. This would lead to a better idea of the kind of funding that would be required for infrastructure adaptation to climate change.