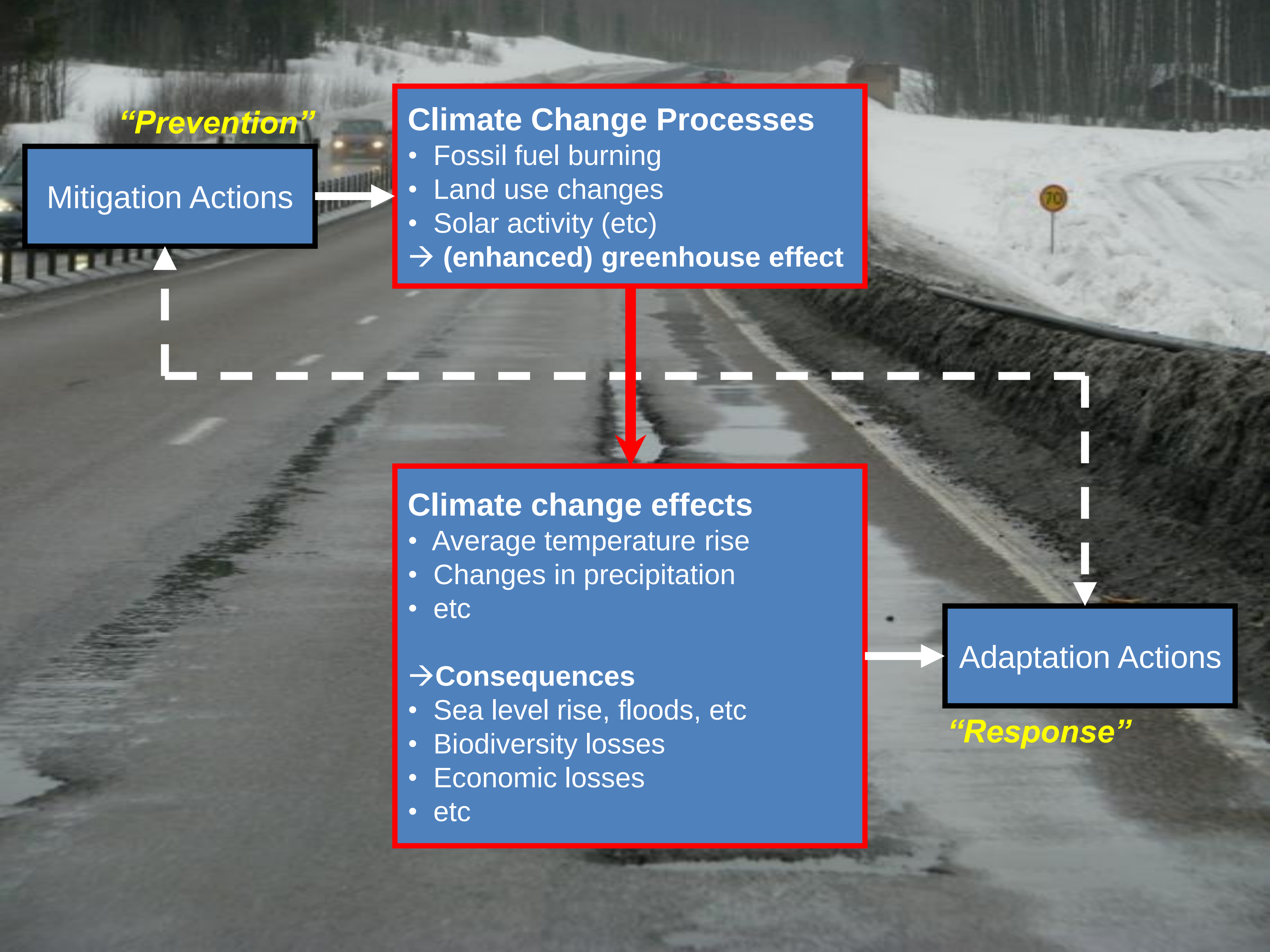
WG – 5 Adaptation to Climate Change

Introduction of WG Activities

World Road Association (PIARC)

Brief to Committee D.2 on Road Pavements:

- Identify aspects of road pavements subject to the impacts of climate change
- Study evolving adaptation strategies



"Prevention"

Mitigation Actions

Climate Change Processes

- Fossil fuel burning
- Land use changes
- Solar activity (etc)

→ (enhanced) greenhouse effect

Climate change effects

- Average temperature rise
- Changes in precipitation
- etc

→Consequences

- Sea level rise, floods, etc
- Biodiversity losses
- Economic losses
- etc

Adaptation Actions

"Response"

PIARC Guideline:
Dealing with the Effects of Climate Change on Road Pavements

Member of Working Group:

Anne Beeldens	Belgium
Cornel Bota	Romania
Peter Bryant	Australia
Richard Elliott	United Kingdom
John Emery	Canada
Franci Kavčič	Slovenia
Kazuyuki Kubo	Japan
László Petho	Hungary
Robert Mesnard	France
Asghar Naderi	Iran
Bryan Perrie	South Africa
Tim Smith	Canada
Rodolfo Téllez	Mexico
Jan Van der Zwan	Netherlands
Benoît Verhaeghe	South Africa
Mats Wendel	Sweden
Bin Hj Sufian Zulakmal	Malaysia

Translators & Editor:

Marie Thérèse Goux	France
Tim Morin	Canada
Rodolfo Téllez	Mexico
Brian Ferne	United Kingdom

Countries who responded to the questionnaire:

Australia, Belgium, Canada, China, Colombia, Denmark, Estonia, Finland, France, Hungary, Japan, Lithuania, Netherlands, New Zealand, Norway, Philippines, Slovakia, South Africa, Sweden and the USA

PIARC Guideline:
Dealing with the Effects of Climate Change on Road Pavements

1. **Introduction**

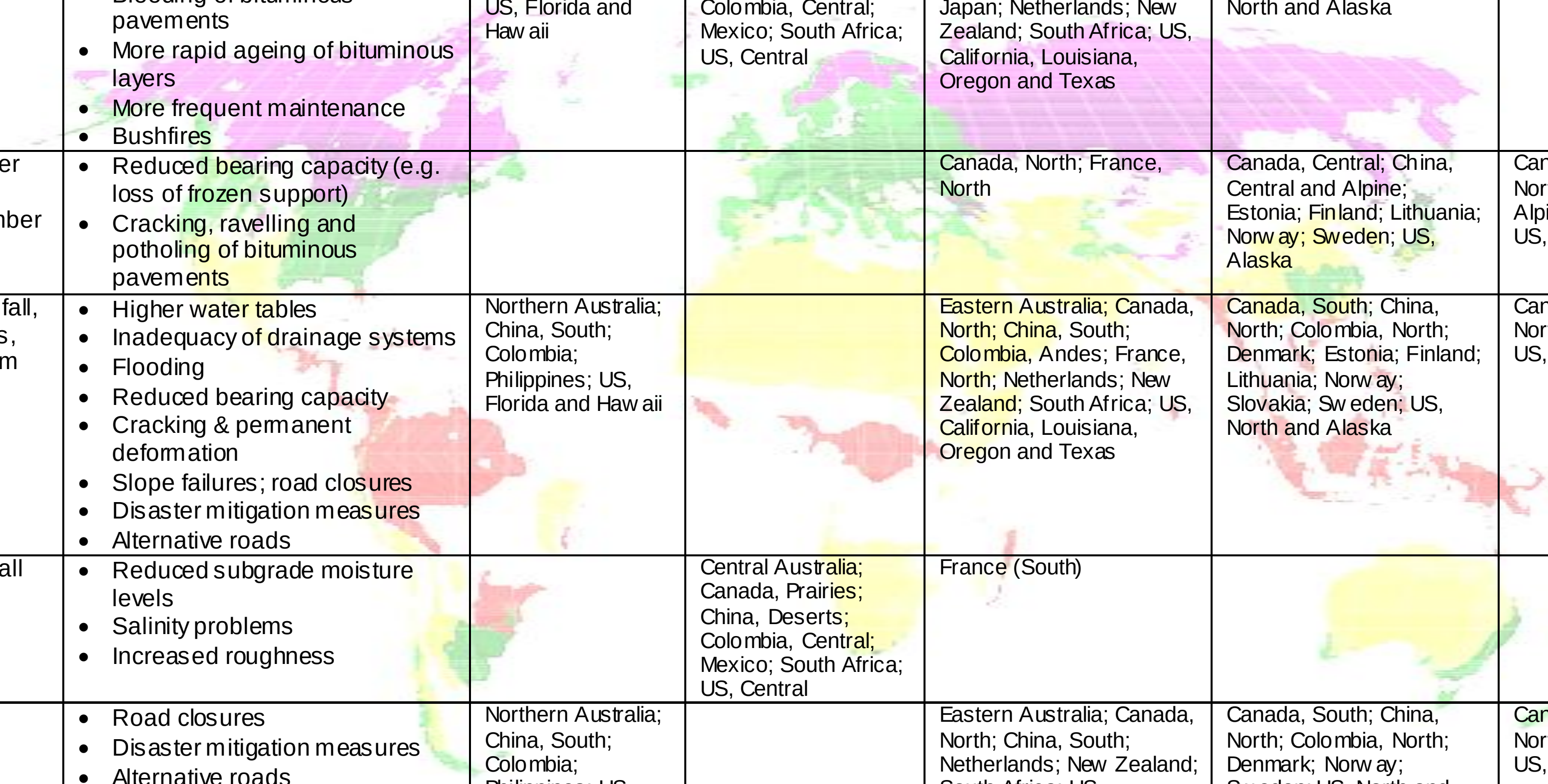
2. **Climate change and its impact on road users**
   - 2.1 Overview on climate change and why it matters to road owners
   - 2.2 Potential climate change impacts on road pavements
   - 2.3 Main concerns raised by road owners

3. **Systematic approach for conducting risk and vulnerability assessments**
   - 3.1 Identification of potential climate change effects
   - 3.2 Assessment of impact of climate change on the vulnerability of road pavements
   - 3.3 Appraisal of risks and identification of potential solutions and strategies to address vulnerabilities
   - 3.4 Implementation of adaptation plans and strategies
   - 3.5 Monitor and review

General concerns raised by road owners

- Addressing the biggest unknown, namely the current **uncertainty of predicting the rate of change of various climatic influences on road pavements and thus where to focus immediate attention** – need for local intelligence on likely effects of climate change
- Methodologies for **assessing risks** associated with climate change and how to conduct vulnerability assessments
- Methodologies for the **mapping of critical/vulnerable infrastructure** and estimating the **costs of climate change**
- Methodologies on **how to design and implement adaptation strategies**
- **Greater sharing of knowledge** amongst key stakeholders on how to deal with the effects of climate change on road infrastructure
- Better linkage of climate change to **asset management**
- Adaptation in the design for future protection of bridges, tunnels, transit entrances and critical evacuation routes, and the provision of alternative routes
- Capacity building in the field of **rapid response to incidents and protection of key assets**

Specific concerns raised by road owners



Climate effects	Impacts raising concern (from questionnaire responses)	Five Main Köppen-Geiger Climate Groups (1976-2000; See Figure 5a)				
		Group A	**Group B**	**Group C**	**Group D**	**Group E**
Increased upper temperatures	• Increased rutting of flexible pavements • Bleeding of bituminous pavements • More rapid ageing of bituminous layers • More frequent maintenance • Bushfires	Northern Australia; China, South; Colombia; Mexico; US, Florida and Hawaii	Central Australia; Canada, Prairies; China, Deserts; Colombia, Central; Mexico; South Africa; US, Central	Eastern Australia; Canada, North; China, South; Colombia, Andes; France; Japan; Netherlands; New Zealand; South Africa; US, California, Louisiana, Oregon and Texas	Canada, South; China, North; Colombia, North; Lithuania; Slovakia; US, North and Alaska	
Increased lower temperatures, increased number of freeze-thaw cycles	• Reduced bearing capacity (e.g. loss of frozen support) • Cracking, ravelling and potholing of bituminous pavements			Canada, North; France, North	Canada, Central; China, Central and Alpine; Estonia; Finland; Lithuania; Norway; Sweden; US, Alaska	Canada, Far North; China, Alpine; Norway; US, Alaska
Increased rainfall, wetter climates, increased storm frequencies	• Higher water tables • Inadequacy of drainage systems • Flooding • Reduced bearing capacity • Cracking & permanent deformation • Slope failures; road closures • Disaster mitigation measures • Alternative roads	Northern Australia; China, South; Colombia; Philippines; US, Florida and Hawaii		Eastern Australia; Canada, North; China, South; Colombia, Andes; France, North; Netherlands; New Zealand; South Africa; US, California, Louisiana, Oregon and Texas	Canada, South; China, North; Colombia, North; Denmark; Estonia; Finland; Lithuania; Norway; Slovakia; Sweden; US, North and Alaska	Canada, Far North; Norway; US, Alaska
Reduced rainfall	• Reduced subgrade moisture levels • Salinity problems • Increased roughness		Central Australia; Canada, Prairies; China, Deserts; Colombia, Central; Mexico; South Africa; US, Central	France (South)		
Sea level rise	• Road closures • Disaster mitigation measures • Alternative roads	Northern Australia; China, South; Colombia; Philippines; US, Florida and Hawaii		Eastern Australia; Canada, North; China, South; Netherlands; New Zealand; South Africa; US, California, Louisiana, Oregon and Texas	Canada, South; China, North; Colombia, North; Denmark; Norway; Sweden; US, North and Alaska	Canada, Far North; Norway; US, Alaska
Increased wind velocity	• Damage to road furniture	China, South; Colombia; US, Florida and Hawaii		Canada, North; China, South; New Zealand; US, California, Louisiana, Oregon and Texas	Denmark; Canada, South; China, North; Colombia, North; US, North and Alaska	Canada, Far North; US, Alaska

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4. Managing climate change impacts on the operation and performance of road pavements

4.1 **How to deal with changes in temperature**
- 4.1.1 Increase in frequency of very hot days and heat waves
- 4.1.2 Decrease in frequency of very cold days
- 4.1.3 Increases in arctic temperatures

4.2 **How to deal with changes in precipitation**
- 4.2.1 Increase in frequency of intense precipitation events
- 4.2.2 Increase in frequency of drought conditions
- 4.2.3 Changes in seasonal precipitation

4.3 **How to deal with other effects**
- 4.5.1 Sea level rise, added to storm surges
- 4.5.2 Increased wind velocity
- 4.5.3 Instability of embankments and slopes

4.1 How to deal with changes in temperature

4.1.1 Increase in frequency of very hot days (and heat waves)

4.1.1.1 Primary and secondary impacts

Primary impacts:

The primary impacts of an increase in frequency of very hot days and heat waves on bituminous pavement layers are manifested by an increased risk of: (1) asphalt rutting; (2) flushing and bleeding of bituminous surfacings, and/or; (3) thermal cracking.

As the temperature of an asphalt mix increases, the bitumen phase loses stiffness. Hence, at the same stress level and load duration, the irrecoverable creep deformations (rutting) caused by static or dynamic traffic loading will accumulate at a faster rate, caused by a combination of mix densification and shear deformation. Traffic induced asphalt mix densification is accompanied by a reduction in air voids, and as the voids content approaches zero percent, the bitumen phase overwhelms the voids network and becomes dominant, resulting in flushing and bleeding. This reduces the contribution of aggregate to aggregate mechanical interlock and causes an increase in the temperature sensitivity of the mix and a major reduction in the stability of the asphalt mix at elevated temperatures, leading to rutting, predominantly in the lower layers (binder and base).

Deep ruts in asphalt pavements are in general a danger to drivers and excess bitumen smearing the surface of the pavement also becomes a driving hazard as it offers very little skid resistance.

The consequences include the need for increased maintenance and repair and also a higher frequency of disruption to traffic flow, which impacts on road user costs.

Higher surface temperatures accompanied by increased intensity and duration of ultraviolet radiation cause an increase in the rate and severity of oxidation and/or hardening of the bitumen phase especially in the upper exposed parts of an asphalt surfacing. The net result is that the binding ability of the bitumen eventually decreases (as it becomes harder and less flexible) and is then less able to withstand the forces induced by traffic and climate. This results in cracking, progressing from micro to macro size, and material loss. Severely cracked surfaces will have reduced bearing capacity, exacerbated by water permeation. Conversely, bitumen hardening may lead to an increase in mixture stiffness with a potential beneficial effect on pavement load spreading ability.

With respect to concrete pavements, an increase in temperatures reduces the time window for casting conventional concrete mixtures due to loss of moisture by evaporation In general an increase in temperature will result in an increase in drying shrinkage cracking for concrete pavements.

Significant diurnal temperature fluctuations will also increase the extent of warping in concrete pavements. Increased warping will result in increased tensile stresses in concrete pavements under traffic loading and ultimately lead to a reduced fatigue life.

Secondary Impacts:

Increased ambient temperatures result in lower asphalt layer stiffness, which results in a greater proportion of the traffic stresses being transmitted to the lower, more vulnerable granular or foundation layers, potentially leading to structural rutting. Unlike surface damage, it is not viable to cosmetically repair or strengthen damage that accumulates in the lower layers of a pavement and major reconstruction operations would be required.

With an increased need for maintenance and resurfacing, the amount of reclaimed asphalt surfacing materials is likely to increase substantially. This may in turn place added pressure on material designers and contractors to attempt to recycle as much of this material as possible into new asphalt mixes.

Extended dry summers can lead to the risk of bush fires. The extent, magnitude and speed at which these wind fuelled fires can spread out of control and engulf housing estates and roads is all too evident from recent examples from the USA, Australia and Greece.,

Global warming is likely to lead to greater shortages of water in some geographical areas; this will drive up the cost of water and simultaneously the cost of construction projects.

Increased global average temperatures may lead to gradual desertification and extinction of certain plant and tree species which, if in the vicinity of road structures, will have consequences on the sub-surface moisture profile of these road foundations. Excessive drying of some soil types may cause shrinkage cracks which in thinly surfaced roads may reflect through the asphalt bound layers. Vegetation deprived areas are more prone to flash floods following even brief intense downpours. Furthermore, arid climates with sparse or diminishing vegetation suffer more frequently from sand storms (e.g. Arabian Gulf Area). The very fine sand/silt particles can stay suspended in the atmosphere for several days severely restricting visibility on roads.

4.1.1.2 Possible short- to medium-term solutions and mitigation techniques

To a large extent, engineers already know how to accommodate other temperatures both in pavement design and in mixture design. A number of possible solutions exist, including the following:

- Adjustment of mix design (performance-related binder selection, including polymer modification of bitumen; selection of stronger aggregate skeleton; optimisation of volumetric criteria);
- Adjustment of structural design (flexible, semi-rigid and rigid/composite designs);
- Adjustment of maintenance plan (e.g. more frequent surfacing; sanding with lime);
- Adjustment of traffic management (e.g. temporary road closures or imposing temporary load restrictions);
- Making greater use of concrete (less sensitive to temperature), while reviewing mixture composition and the application and curing of concrete at higher temperatures, and the need for additional reinforcement to prevent/control warping;
- Adoption of binders with higher softening point for surface dressings and asphalt;
- Adjustment of construction processes and timing;
- Forced cooling of pavements;
- Adoption of solutions from elsewhere.

This last point relates to a climate analogue, which is a current climate that is similar to the projected future climate of a given location. One such climate analogue for London (Hallegate et al, 2007) suggests that the climate in London at the end of the century might be like that of Nantes according to one model, or Lisbon according to another. If it assumed that Nantes and Lisbon are well adapted to their current climates, then by studying their current road networks and the way they are managed, it is possible to gain an insight into the possible adaptation measures that could be required in the south of the UK. In reality, any temperature change will be gradual and structural design is less important in the short to medium term; the most significant imminent risk is likely to be rutting, resulting from (short term) heat waves.

Current pavement design methodologies make use of historical climate data to predict the diurnal temperature and precipitation regimes. A case can be made to perform sensitivity analyses of the influence of climate change on the long-term performance of pavements instead of only using static climate data. This type of analysis would allow a better understanding of the potential influence of a future increase in rutting, freeze-thaw cycles, frost heave and thermal cracking on the functional life of the pavement. However, current design methods are mainly empirical and are unable to predict, for example, rutting. A better model for predicting degradation and therefore a better understanding of degradation mechanisms is therefore needed in the long term.

The importance of good construction practice cannot be over-stated, particularly when introducing harsher/drier mixes or stiffer binders. With such mixtures, there may come a point beyond which modified or upgraded asphalt mixes become too difficult (unworkable) to compact in the field using conventional compaction equipment, and a new generation of ultra-heavy compaction equipment may need to be introduced. A related issue is that, in service, the performance of some asphalt mixes is adversely affected by their inability to resist densification, especially during the initial stages of their lives. A key feature of future design and construction practice should be the production of asphalt mixes that can be laid and compacted at their final (refusal) density on day one, i.e. mixes designed, laid and compacted to achieve instantaneous full interlock, and that will not densify any further as a result of loss of air voids content caused by traffic loading. It should be noted that in some locations and with some mixtures (porous asphalt) this problem of densification is not experienced; other countries may be able to learn from this experience.

Various techniques are available for reducing the temperature of the surfacing which, in addition to mitigating rutting, flushing and thermal cracking, could be beneficial to reduce the heat island effects in urban areas. These techniques include:

- Cooling pavements with water: trials in Japan have shown that by simply spraying pavements with water during the day, it may be possible to keep the pavement temperature low. Some cities have also used treated wastewater[1].

- Using pervious surface courses. Due to the open structure, the layer is not heated in the same way as in dense asphalt mixes and, to a certain extent, the mix is cooled by the ambient air so preventing heat accumulation in the surface course and lower layers (see Box 2).

- Application of chip seals, which consist of aggregate bound in liquid bitumen. These are often used to resurface low-volume asphalt roads and sometimes highways. Solar reflectance of chip seals will correlate with the albedo of the aggregate used.

- Exposing the aggregate by removal of the bituminous binder film coating the aggregate.

- Application of whitetopping (thin concrete surfacing) over existing asphalt offers good solar reflectance.

- Application of microsurfacings (thin sealing layers used for road maintenance). Light coloured materials can be used to increase the solar reflectance of the asphalt. One trial has shown that the application of light-coloured microsurfacing material consisting of cement, sand, other fillers and a liquid blend of emulsified polymer resin, has produced solar reflectance values comparable to that of new concrete[1].

- Increasing the solar reflectance of conventional asphalt by the use of light-coloured aggregate, colour pigments or coloured sealants. Solar reflectance in low trafficked and parking lots can also be effectively improved by the use of alternative resin-based pavements (clear coloured tree derived resins). Using clear resins, albedo becomes mainly determined by aggregate colour.

4.1.1.3 Possible longer-term solutions

In addition to the above, a number of other, probably more long-term, solutions could be adopted to deal with the increase in frequency of very hot days and heat waves. These include:

- The application of purpose designed solar reflective coatings that can be sprayed on conventional asphalt surfacing (Heat-Shield Pavements). The coatings have high reflectivity in the near infrared spectra and low reflectivity in the visible light spectra (see Box 1).

- The use of non-vegetated and vegetated permeable pavements (see Box 2).

- The use of Water Retention Pavements (see Box 3). Trials in some Japanese cities have shown that pavement temperatures may be effectively kept low by using water retention pavements. Water retention pavements are porous asphalt or concrete based pavements which have a sublayer that consists of water retentive materials that absorb moisture and then evaporate it through capillary action when the pavement heats up. Some of these systems involve underground water piping to ensure the pavement stays moist.

- More sophisticated cooling of roads in summer and using the stored heat to warm the road in winter and/or generate energy.

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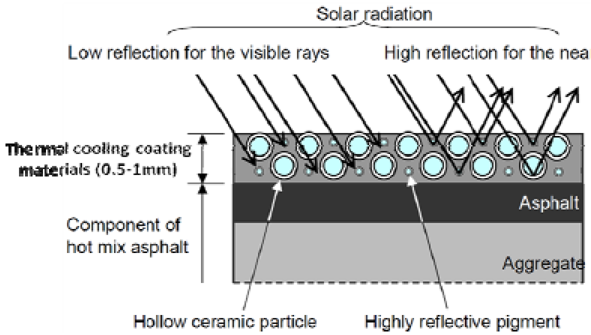
[1] Wong E., et. al., "Reducing Urban Heat Islands: Compendium of Strategies", Climate Protection Partnership Division in the US Environmental Protection Agency's Office of Atmospheric Programs.

Box 1: Pavement Surfaces Coated with Solar Reflective Technology[2,3]

The innovative technology behind this Japanese spray-on coating is based on higher reflectivity for near infrared rays and lower reflectivity for the visible rays. The advantage is that normal road markings can be used since the pavement surface appears dark. The coating formulations essentially consist of high albedo paints which reduce the ability of the pavement surface to absorb infrared rays; furthermore the compositions contain fine hollow ceramic particles to reduce the thermal conductivity of the coating. The technology has also been referred to in the literature as "Heat-Shield Pavements". In one investigation, the albedo of a Heat-Shield surfacing has been measured to be as high as 0.57 (compared to 0.07 for a conventional drainage pavement).

In another set of week-long outdoor exposure trials it was demonstrated that during the summer season with air temperatures reaching approximately 35°C (no rain), the surface temperature of conventional (uncoated) asphalt slabs peaked at around 60°C, whilst identical slabs that had been pre-coated with the solar reflective technology had maximum surface temperatures of around 40°C. The paints were shown to have adequate adhesion to both old and new asphalt surfacing and full scale trials have shown the skid resistance to be comparable to conventional asphalt surfacing. Accelerated ultraviolet weathering tests also showed good weather resistance. The skid resistance of these spray-on coatings was enhanced by introducing a thin layer of ceramic sand sandwiched in between two reflective coating layers.



Schematic of solar reflective technology

- Greater use of transparent bitumen derived binders. Colourable binders have been manufactured from petroleum resins, petroleum oils and thermoplastic elastomers. The components are well mixed and dispersed to produce a stable product. Adhesion promoters and antioxidants can be introduced into the formulations if needed[4].

- The application of lower and stricter limits on maximum permissible axle loads and tyre pressures in combination with tougher measures to monitor traffic loading.

- The removal of as much as possible of the heavy goods traffic from the road network onto other means of transportation (particularly rail, inland waterways and sea).

- Traffic management so as to prevent very slow moving/standing heavy goods traffic and distribute the traffic loading more uniformly across all traffic lanes.

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[2] Iwama M., Yoshinaka T., Omoto S., Nemoto N., "Fundamental study on the reduction of pavement temperature by use of solar reflective technology", International ISAP Symposium on Asphalt Pavements and Environment, 2008, Switzerland, pp. 83-93.

[3] Kawakami A. and Kubo K., "Development of a cool pavement for mitigating the urban heat island effect in Japan", International ISAP Symposium on Asphalt Pavements and Environment, 2008, Switzerland, pp. 423-434.

[4] Seo A., Morikubo M., Aoki H., "New colourable binder with durability and environmental suitability", The 6th International Conference on Road and Airfield Pavement Technology, 20-23 July 2008, Sapporo, Japan.

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5. Policy implications

- 5.1 How to respond to potential impacts of climate change
- 5.2 How to deal with uncertainty and risks
- 5.3 Adaptation of design rules and specifications
- 5.4 Traffic management issues and safety
- 5.5 Education for climate change adaptation

6. Conclusions and recommendations

7. References

Appendix: Questionnaire responses

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Conclusions:

- **Climate change**, and especially extreme weather events, **will impact on the costs of operating a road network**
- Road owners/operators should **quantify their risk profile** (economic value of assets & cost to society)
- Differentiate between **existing and new infrastructure** – risk profile will dictate which actions would require immediate attention
- Technical solutions are readily available – make use of **climate analogues** to import from elsewhere
- Greater **exchange of information** on how to deal with effects of climate change is encouraged
- Since climate change is fast becoming a reality, there is a need to **start acting now**

WG-5 Adaptation to Climate Change

Status Report

- English and French version of the technical guideline have been completed and submitted to PIARC for publishing. Spanish version to follow soon.
- Call for papers for the Congress resulted in 23 submissions of which 21 were accepted
- Poster session will be held on Friday between 9:00 and 12:30
- Four papers selected for presentation in this session

Paper Presentations

- **Yves Ennesser, Egis, France**
  Adapting Road Infrastructure to Climate Change: Innovative Approaches and Tools

- **Alexander Zeissler, Dresden University of Technology, Germany**
  Impact of Climate Change on the Development of Rutting

- **Patricia Irrgang, USA**
  Pavement Preservation Processes in Latin America: Energy Use and Greenhouse Gas Emissions

- **Masahiko Iwama, NIPPO Corporation, Japan**
  Use of Solar Heat-Blocking Pavement Technology for Mitigation of Urban Heat