A FRAMEWORK FOR ASSESSING THE RISK TO TRANSPORT INFRASTRUCTURE FROM THE GREENHOUSE EFFECT AND DEVELOPING ADAPTATION STRATEGIES

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Abstract: Most scientists accept that anthropogenic production of carbon dioxide and other greenhouse gases will have (and is already having) an effect on climate. These climatic changes have potentially significant implications for transport infrastructure. Despite the significance of the potential impacts of the greenhouse effect, most research has focused on climatic modelling and issues such as the prominence of the transport sector as a greenhouse gas producer and mitigation strategies. There has been comparatively little consideration of adaptation strategies and planning processes to 'greenhouse proof' key transport infrastructure and systems. This paper describes a framework for assessing local and regional risks to transport infrastructure and developing adaptation strategies to counteract the likely impacts. The paper will be of strong interest to many countries of East Asia which have transport infrastructure that is vulnerable to the effects of more extreme weather that may result from the enhanced greenhouse effect.

1. BACKGROUND

Water vapour and a range of gases (including carbon dioxide, methane and nitrous oxide) absorb thermal radiation emitted by the earth's surface and re-emit part of this energy downwards and warm the surface. The resulting natural greenhouse effect keeps the present average surface temperature of the earth considerably warmer than if no greenhouse gases were present. However there is clear evidence that the concentrations of greenhouse gases in the atmosphere are increasing as a result of human activity. Most scientists accept that this anthropogenic production of carbon dioxide and other greenhouse gases will have (and is already having) an effect on climate. Possible consequences of the greenhouse effect include:

- increased average temperatures and greater temperature extremes
- higher sea level
- changes in rainfall distribution and intensity
- greater intensity of cyclones, typhoons, and extreme winds
- increased storm surges
- more unpredictable and unstable weather patterns.

These climatic changes have the potential for significant impacts on transport system throughout eastern Asia in terms of:

- infrastructure condition and operation (bridges, pavements, rail track, cuttings, embankments, wharves, channels, sea walls, river crossings, etc)
- infrastructure longevity and maintenance requirements
- damage caused by severe weather events
- design and quality standards for construction and maintenance
- protection measures to mitigate adverse impacts on infrastructure
- possible relocation of existing infrastructure
- planning policies, principles and guidelines for new infrastructure
- potential disruption of access to regional centres with adverse effects on the community and the economy.

Despite the significance of these potential impacts of the enhanced greenhouse effect, most analysis has focused on direct climatic effects and issues such as the prominence of the transport sector as a greenhouse gas producer and mitigation strategies. There has been comparatively little consideration of adaptation strategies and planning processes to 'greenhouse proof' key transport infrastructure and systems. A notable exception is Thornes (1997).

This paper describes a framework for assessing risks to transport infrastructure from climate change at a regional or national level, and developing adaptation strategies to counteract the likely impacts.

2. RISK AND RESPONSE

The assessment of the risk to transport infrastructure from the effects of climate change is fundamentally the same process as assessing risks from other potential sources. Therefore standard approaches to risk assessment and response can be applied.

Risk can be defined in many different ways. One of the most useful definitions describes risk as 'the potential for the realisation of the unwanted, negative consequences of an event' (Rowe 1977). Therefore risk occurs as a result of a chain of causal effects as illustrated in Figure 1.

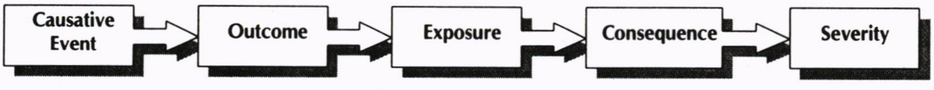

Figure 1. Chain of Causal Effects

For example, a *causative event* (such as the enhanced greenhouse effect) may produce an *outcome* (such increased rainfall intensity) which may have an effect on *exposed items* (such as roads) potentially having adverse *consequences* (such as road inundation) whose *severity* will depend on the degree of negative impact of the specific risk consequence in the particular situation. The appropriate response will then depend on an evaluation of the severity of the consequences in the context of the risk situation.

In line with the model described above, the risk assessment and response process has four essential steps:

1. *Define* the risk situation, in terms of causative events, outcomes and exposure and consequences;
2. *Estimate* of the risk potential in terms of its magnitude and probability of occurrence;
3. *Assess* the significance of the risk; and
4. *Respond* in an appropriate manner, according to whether the risk is acceptable or should be controlled or ameliorated.

If a response is considered to be appropriate then there are three ways that risk can be controlled:

1. *Modify* physical features of equipment and environment;
2. *Change* the organisation and administrative practices within which the risk exists; or
3. *Manage* the behaviour of people who interact with the system.

This generic framework can form the basis of risk evaluation for a wide range of situations. The remainder of this paper discusses how the generic risk assessment framework can be applied in the context of climate change risk assessment; generic response strategies; and strategies for overcoming potential barriers to implementing the proposed approach.

3. THE RISK ASSESSMENT PROCESS

The risk assessment and response process can be described in terms of four steps.

STEP 1: DEFINE THE CLIMATE CHANGE RISK SITUATION

The effects of climate change on transport infrastructure are potentially numerous, varied and complex. Transport infrastructure encompasses all modes and a wide variety of engineering and operational elements. In turn, these elements will be affected in different ways by a range of climatic events whose frequency and intensity will vary between climatic and geographic regions. Therefore the first step is to identify and define the risk situation, in terms of causative events, outcomes and exposure and consequences. The situation can be described in terms of

- climatic events and outcomes; and
- infrastructure exposure and consequences.

Step 1.1 Define Infrastructure Categories and Consequences

Although climatic change is the causative event driving the risk situation, the best place to start the process of defining the risk situation is with the transport infrastructure. The first step is to address the following questions:

- what types of transport infrastructure exist in the region under consideration;
- what aspects of the infrastructure may be affected by climatic factors; and
- what climatic factors cause the effects.

From an engineering perspective, transport infrastructure can be taken to include fixed facilities that support transport operations. In general, each mode of transport has different infrastructure requirements and its own dedicated facilities, which means that transport infrastructure can be classified and assessed on a modal basis. The set of infrastructure categories may vary from place to place but for the purposes of assessing the climate change risk, the following set of categories provides a good starting point:

- Roads (pavements, earth works, drainage, signage, etc)
- Railways (track, earth works, drainage, etc)
- Bridges (road, rail, etc)
- Airports (runways, buildings, navigational aids, etc)
- Sea Ports (channels, seawalls, navigational aids, etc)
- Offshore Shipping (channels, navigational aids, etc)
- Rivers Transport (jetties, channels, navigational aids, etc)
- Pipelines & Conveyors
- Other (cable cars, monorail, etc)

Note that Bridges have been extracted as a separate category because the bridge components of road and rail infrastructure share common characteristics and similar climate change risks, and are inherently different to the road and rail track component. Also note that at this stage, the aim is to compile a comprehensive set of transport infrastructure categories without reference to potential climatic effects.

The second question concerns the aspects of transport infrastructure that may be affected by climate change. Climatic factors are considered during planning, construction, maintenance and operational phases of the transport infrastructure life cycle. Therefore the potential impacts of climate change can be assessed in relation to their effect on infrastructure:

- *Location* = where the infrastructure is constructed. A key aspect of transport infrastructure planning is site selection, which routinely involves consideration of climatic factors.
- *Design* = the impact on design standards. Climatic factors are taken into consideration during the design process and may have an impact on design details and construction costs.
- *Condition* = the effect of climatic factors on the condition of the infrastructure, including rate of deterioration, maintenance, lifespan, and so on.

- *Operation* = the effect on transport activities associated with the infrastructure, including operation of cars, buses, trucks, trains, ships, and ferries, aircraft and so on.

The combination of transport infrastructure categories and aspects of location, design, condition and operation provide a basis for the exposure and consequences aspects of the risk assessment framework. The next step is to identify the potential range of climatic variables that will have an effect on the categories of transport infrastructure.

Step 1.2 Identify Climatic Events and Outcomes

The underlying causative event is the enhanced greenhouse effect. It is difficult to make broad generalisations about the likely outcomes of the greenhouse effect because of local climatic variability, however the fundamental effects are predicted to be

- global warming
- increased climatic volatility and extreme weather; and
- increased severity of large scale systems such as tropical cyclones.

These effects translate into potential changes in key climatic variables that may have a significant impact on transport infrastructure location, design, condition or operation. Relevant climatic variables include:

- rainfall
- winds
- temperature
- snow and ice
- dust storm
- storm surge
- flood frequency and severity
- sea level
- sea waves

These variables can form the basis of a long list of potentially significant climatic variables relevant to a particular situation. Note that the list is an inventory of climatic variables that are the end-result effects of weather events and climate change, irrespective of their origin. Combined effects, such as storm surge on top of sea level rise, can be included as separate categories or covered under the more extreme of the effects (in this case storm surge).

Because current and possible future climate is significantly effected by local conditions especially latitude, altitude and proximity to major oceans, the list of climatic variables and their potential consequences will vary with location. If the area to covered by the risk assessment is climatically diverse then the evaluation should be decomposed into several separate regional risk assessments. The regions may be geographically large but should be internally consistent in terms of large scale climatic patterns. For example, Queensland which covers an area larger than Thailand, Laos, Cambodia and Vietnam combined was divided into four climatic regions for the purposes of climate change risk assessment.

Step 1.3 Preliminary Risk Exposure Assessment

The combination of infrastructure category, type of impact, climatic factors and regions provides a structured framework for evaluating climate change risks and developing adaptation measures. But not all combinations are equally significant. The various types of transport infrastructure will be affected by climatic factors to differing degrees and there is not equal scope to usefully respond to possible climate changes. In other words, the transport infrastructure varies in terms of its vulnerability and exposure to the effects of climate change and in the ability to reasonably do something about it. For example, the design of bitumen pavements will not be significantly affected by any foreseeable increase in extreme winds. Likewise, snow and ice is unlikely to be a significant climatic factor for tropical regions, and dust storms may be a significant problem in some locations but there is little that can be usefully done in response to the effect on roads of a predicted increase in dust storm frequency.

It is recommended that a preliminary risk and response assessment should be undertaken at this stage of the process. The aim is to identify key transport infrastructure categories and key climatic variables where there is potentially a significant effect and viable response. Other infrastructure categories and climatic variables can then be droppped from further analysis. Resources available for risk assessment and development of adaptation measures can then be targeted at those situations with significant risk potential from climate change and scope for implementing effective responses.

A suggested approach for identifying significant risks is to consider each combination of infrastructure category and climatic variable and make a qualitative assessment of the risk and response potential based on professional judgement. For the Queensland risk assessment, the preliminary assessment were structured using a tabular format, as shown in Figure 2. Each combination of infrastructure category and climatic variable was considered by a team of experts in the various transport modes. A 'cross' in each box corresponding to a combination where it was considered that there was potential for a significant effect. The pattern of effects was then clearly evident from the Table and key infrastructure categories and climatic variables could be readily identified, and others dropped.

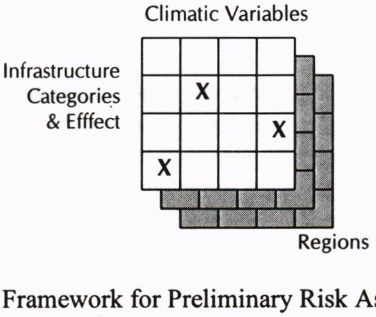

Figure 2. Framework for Preliminary Risk Assessment

The preliminary analysis undertake for the Queensland risk assessment uncovered several significant conclusions that may be transferable to other locations. In general terms, the preliminary analysis undertaken to identify the set of key climatic factors indicated that

- extreme short-term weather events (rain, wind, temperature, storm surge, flood, waves) have the greatest effect on transport infrastructure;
- longer term weather events (such as droughts) and climatic trends (such as small changes in average temperature and rainfall) have limited impact on transport infrastructure; and
- sea level rise will be a slow process and in most cases (except very low lying coastal areas) can be adapted to in terms of infrastructure, location and design. However sea level rise can have very significant impacts in combination with storm surges and sea waves.

STEP 2: ESTIMATE THE RISK POTENTIAL

The next step is to quantify the risk potential in terms of the scale and likelihood of climate change related to the enhanced greenhouse effect. In simple terms, the risk potential is related to the magnitude of expected changes in climatic variables, and their timing. There has been a major international research and cooperative modelling effort devoted to the forecasting future climate conditions. Models exist at several levels. Global climate models (GCMs) address general circulation patterns and heat balance issues, and can be coupled with regional climate models that higher resolution results for a particular region. The models represent processes linking the atmosphere, ocean and biosphere both vertically and horizontally. The major outputs of the models are trends in key climatic variables for up to the next 100 years.

Climate change will depend on the interaction between natural forces and human activities. There is no definitive forecast of how human activity will evolve over the next century so the GCMs work on the basis of a range of internationally agreed scenarios that define an envelope of possible futures. The scenarios are defined by the Intergovernmental Panel on Climate Change (IPCC) and correspond to different sets of assumptions relating to:

- population growth;
- growth of economic activity;
- improvements in energy efficiency;
- structural changes in the world economy; and
- future costs of fossils fuels and alternative energy sources.

Figure 3 shows a typical forecast of a climatic variable, in this case sea level rise.

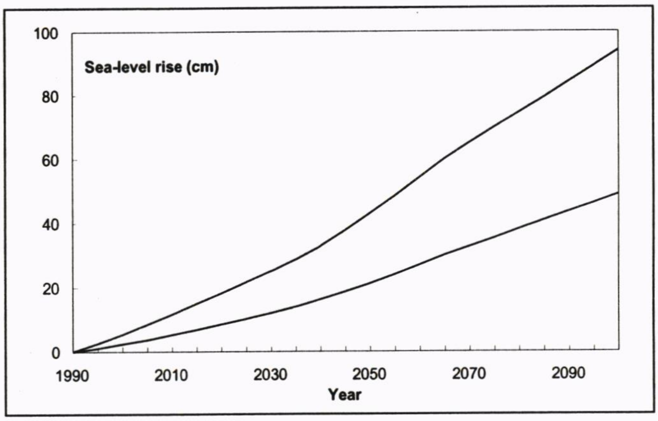

Figure 3. Forecasts for Sea Level Rise

The upper bound of the envelope of forecasts corresponds to a scenario of moderate population growth, strong economic activity, high fossil fuel availability and a phase-out of nuclear power. Similarly, the lower bound corresponds to low population growth, lower rates of economic growth and implementation of greenhouse gas and energy consumption reduction policies. The various scenarios correspond to alternative possible futures; any one of which may eventuate. Therefore it is invalid to interpret the envelope of scenarios in terms of probability bounds. That is, it is invalid to assume that outcomes close to the upper and lower bound of the envelope are less likely to occur than outcomes mid-way between the bounds, or that a line through the middle of the envelope is the most likely trend. Therefore for the purposes of risk assessment, it is prudent to assume the worst and use the upper limit of the envelope of forecasts.

The graph also illustrates the inherent uncertainty in the forecasts. Over time the difference between the upper and lower bound increases in line with growing uncertainty. This effect is known as the 'uncertainty explosion' (Jones et al, 1998) and results from cumulative uncertainties associated with global climate sensitivity, emissions scenarios and regional variability. As GCMs improve and better information becomes available, the range of uncertainty can be expected to reduce.

The outputs from climate modelling provide a quantitative basis for assessing the severity of risk to transport infrastructure. It is difficult to make broad generalisations about the likely outcomes of the greenhouse effect because of local climatic variability, however the fundamental effects are predicted to be

- global warming
- sea level rise
- increased climatic volatility and extreme weather; and
- increased severity of large scale systems such as tropical cyclones.

STEP 3: ASSESS THE RISK SEVERITY

The results of global climate modelling indicate that significant changes in climatic variables are a possibility. However the existence of these projected climatic changes does not automatically translate into a significant risk for transport infrastructure. The level and severity of risk will be influenced by:

- the extent of climate change as measured by variations in key climatic variables and regional variations;
- the level of exposure to that risk which will largely depend on the location of the infrastructure;
- the vulnerability of the infrastructure in terms of the inherent tolerance to changes in climatic conditions; and
- the timing of the risk occurrence.

Therefore the next step is to assess each combination of climatic variable and transport infrastructure category in terms of the likelihood of occurrence of the risk, consequences of the risk, and overall severity of risk if no adaptation measures are implemented. As noted above, it is prudent to conduct the risk assessment on the basis of the upper bound of likely climate change impacts. While this approach may accentuate the level of risk in some instances, it provides reasonable certainty that all significant sources of risk are identified. If the upper bound of forecast climate change is adopted and it is assumed that no adaptation measures have been implemented, then the results of the risk assessment represent the worst case scenario of greatest likely climate change. This scenario provides a basis for identifying those instances where adaptation measures may be required to "greenhouse proof" transport infrastructure from the future effects of climate change.

Risk Assessment Procedure

The results of climate modelling provide a quantitative indication of potential changes in climatic variables but the evaluation of risk likelihood, consequences, and overall severity is a qualitative process. The risk rating will be largely based on professional judgement by experts in the field. A suggested technique for creating consistency and objectivity in the risk assessment process is to conduct the evaluation within the framework of an established risk management standard. Risk assessment is a common engineering procedure and many countries (and individual organisations) have established generic risk management standards which can be applied to a range of situations. Typically these standards outline a generic procedure for risk assessment and management and defines the following qualitative scales for assessing likelihood of occurrence of the risk, consequences of the risk, and overall level of risk, as shown in Tables 1, 2 and 3.

Table 1. Qualitative Measures of Likelihood

Level	Description	Description
A	Almost certain	The event is expected to occur in most circumstances
B	Likely	The event will probably occur in most circumstances
C	Moderate	The event should occur at some time
D	Unlikely	The event could occur at some time
E	Rare	The event may occur only in exceptional circumstances

Table 2. Qualitative Measures of Consequence or Impact

Level	Description	Impact
1	Insignificant	Low damage or financial loss
2	Minor	Medium damage or financial loss
3	Moderate	High damage or financial loss
4	Major	Major damage or financial loss
5	Catastrophic	Huge damage or financial loss

Table 3. Qualitative Risk Assessment Matrix

	Consequences				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	S	S	H	H	H
Likely	M	S	S	H	H
Moderate	L	M	S	H	H
Unlikely	L	L	M	S	H
Rare	L	L	M	S	S

LEGEND: H = High risk; detailed research and management planning required at senior level.
S = Significant risk; senior management attention needed.
M = Moderate risk; management responsibility must be specified
L = Low risk; manage by routine procedures

It should also be noted that since the predicted effects of climate change increase over time, see Figure 3, it will be necessary to repeat the analysis at several time intervals. For example, a climate change risk assessment conducted recently for Queensland in northern Australia involved undertaking risk assessments for the following years: 2030, 2070 and 2100. The overall results of the Queensland risk assessment were that the potential effects of climate change are likely to be noticeable by 2030 and generating significant risks to most transport infrastructure categories by 2070 if no adaptation measures are implemented. In part, the higher risks after 2030 are due to uncertainties in climate change scenarios with large variations in key climatic variables.

STEP 4: RESPONSE STRATEGY

For those combinations of transport infrastructure and climate factor where the risk assessment indicates that a significant to high risk exists, the final step is to devise an appropriate response strategy.

The value of the risk assessment in Step 3 is to highlight when and where significant risks are likely to occur, but the results must be viewed in conjunction with a number of other factors when developing the response strategy and strategic action plan. These factors include

- the expected timeframe over which the transport facility will continue to exist at that location;
- the design life of the transport infrastructure;
- the timing of climate change risks;
- cost of implementation; and
- uncertainty in climate change forecasts.

The design life of transport infrastructure elements provides a measure of the planning horizon for considering the effects of climate change for particular infrastructure categories. The typical design life of transport infrastructure is shown in Table 4.

Table 4. Infrastructure Design Life

Type of Infrastructure		Design Life (years)
Roads		40
Rail track		50
Bridges		100
Airports	- Pavements	40
	- Other	50
Sea Ports		50
Pipelines & Conveyors		50

Therefore some types of infrastructure, such as road pavements, have a relatively short design life and may be reconstructed several times over the 100 year timescale considered in climate change modelling studies. Therefore pavements that are being constructed now do not need to be designed for climatic extremes expected in 2100 but may need to be designed for the likely climate at 2030. At the other extreme, bridges have a 100 year design life, and may require some action now to respond to potential climate changes expected at 2100. Therefore the combination of design life and timing of climate change impacts and their associated risks is an important factor in designing a response strategy because it determines what needs to be done now and what can be delayed.

However many transport facilities currently in place or in the planning process will continue to exist at the same location for a hundred years or more, even if the infrastructure is periodically reconstructed. Therefore in framing adaptation strategies, a distinction should be drawn between the location of the transport facility, and design and operation of the transport infrastructure at that location. This distinction is important because the ramifications of location and design decisions may have different timeframe relative to the timeframe for climate change.

The cost of implementation is also an important consideration in the development of responses because limited budgets will be available to fund the cost of strategic actions or potential adaptation measures. Adaptation measures must be affordable and cost effective. For example, it may be cost effective to accept more frequent flooding of a particular road in the future, rather than to relocate the road, construct an alternative route, or raise the road level. In some cases, it is possible to design adaptation measures that have little net budget impact or whose cost can be spread over a long period. For example, the solution to the example of the flooded road may be to progressively improve drainage in the course of normal maintenance works.

Finally, the inherent uncertainty in the forecasts of climate change variables should also be considered. The uncertainty exists at multiple levels. Sources of uncertainty include our imperfect understanding of the climate change process and the future of human society; limitations inherent in computer models; and local climate variability that is not captured in the computer models. As a result, the current climate change forecasts have a large degree of uncertainty and the level of uncertainty varies between climatic variables. For instance, forecasts of global sea level rise have a higher level of certainty than forecasts of local rainfall intensity. Since the risk assessment is based on forecasts, the relative level of confidence in the forecast should be a factor in determining the relative priorities of adaptation initiatives.

The results of the risk assessment and consideration of the factors mentioned above will indicate an appropriate level of response corresponding to the perceived level of risk and the urgency and cost effectiveness of implementing adaptation measures. The response options range from 'do nothing' to immediately modifying existing infrastructure. Adaptation strategies for transport infrastructure at a given location can be structured into a hierarchy of four levels of possible responses:

1. Do Nothing.
2. Watch, Wait & Prepare.
3. Set the Standard for the Future.
4. Intervene Now or in the Future.

The hierarchy of possible responses is described in Table 5.

Table 5. Hierarchy of Possible Adaptation Responses

1. Do Nothing	The lowest level response is no response. This corresponds to an assessment that the perceived risk is too low to be of immediate concern or that any likely risks are so far into the future and so uncertain that no initiatives are required at this stage.
2. Watch, Wait & See	The next level is to monitor developments in climate change forecasts and initiate preparatory investigations. This corresponds to assessment that significant risks may occur in the future and the appropriate response should be undertaken to prepare for their possible occurrence without taking any immediate initiatives directly aimed at climate change adaptation. Examples of monitoring and preparatory tasks include: ▪ monitor progress in climate change forecasting and periodically reassess climate change risk and adaptation strategies in the light of new information; ▪ maintain records of climate-related effects on the transport system, such as, incorporating weather conditions in road accident data; ▪ identify the critical elements of the local transport network; ▪ identify and monitor transport infrastructure that is most vulnerable to current climatic extremes since this infrastructure will become even more vulnerable if climatic extremes become more pronounced; and ▪ investigate technologies appropriate for likely climate change, for example, improved road pavement mix designs for increased average and extreme temperature conditions)
3. Set the Standard for the Future	If there are perceived to be significant future risks from climate change but a lengthy period before adverse consequences are realised, then there is time to prepare. An appropriate response would be to gradually adapt transport infrastructure by implementing design standards and management strategies suitable for expected future climatic conditions. Examples include: ▪ specify and implement new design standards (standards, temperature, wind, etc) for maintenance, new construction and major rehabilitation works; ▪ embed consideration of the effects of climate change and 'best guess' climatic parameters into the transport infrastructure planning process; and ▪ develop infrastructure management plans that take account of the possible impacts of climate change.
4. Intervene	This is the highest level of response. It corresponds to a perceived risk that is sufficiently severe and immediate that intervention is required now or in the near future to counter the risk. The type of intervention may include relocation or reconstruction of infrastructure (such as roads and rail lines) or retro-fitting of existing infrastructure to withstand possible climatic impacts (such as bridge strengthening). Compared to the other levels, this is a high cost and immediate response that would only be appropriate for potentially catastrophic risk levels.

The adaptation strategy for a particular region can then be constructed by assigning one of these generic responses to each transport infrastructure category.

In addition to the specific adaptation responses for design, maintenance and operation of transport infrastructure, there is also a general transport planning dimension. The potential scope and severity of impacts suggest a need to include consideration of the effects of climate change in transport infrastructure planning studies, particularly long term network planning and decisions about the location of major infrastructure elements. Although the design life of most transport infrastructure is less than 50 years, it is likely that a transport facility will be in place at the designated location for a much longer period. Therefore decisions about the siting of major infrastructure needs to take a much longer view than engineering design of the infrastructure once its location is decided. In particular, projected increases in sea level and flood severity for the year 2100 should be taken into account in current decisions about the location of major transport infrastructure.

7. BARRIERS TO IMPLEMENTATION

It appears to be the case that climate change will have an increasingly significant effect on transport infrastructure. However in accordance with its status as an emerging transport issue, the institutional, information, technical and financial bases for climate change risk assessment are currently not well established. This paper has made some progress towards establishing a framework for risk assessment and adaptation but there are likely to be a range of barriers to implementing a climate change adaptation program. Some of the potential barriers to the implementation of response strategies and possible solutions are summarised in Table 6.

Table 6. Potential Barriers and Possible Solutions

Category	Possible Barriers	Possible Solutions
Institutional	• Likely differences in the perceived urgency of considering the potential effects of climate change	• Build awareness of climate change risks firstly within your agency and then with other transport agencies
	• Overlapping responsibilities, with many agencies involved in planning and development of regional transport system.	• Address climate change impacts within your agency as a first step then progressively involve all relevant agencies in developing planning and response procedures
	• Inertia in processes for changing design and other planning standards	• Develop and awareness of the need for planning procedures and design standards that consider likely future climatic conditions as well as historical data

Table 6. Potential Barriers and Possible Solutions (Continued)

Information	• Lack of information about the current scale, scope and cost of climatic impacts on transport infrastructure	• Undertake baseline studies.
Technical	• Uncertainty in forecasts of climate change	• Monitor progress in modelling and incorporate new results in planning procedures.
	• Uncertainty in the effects of increased climatic extremes on transport infrastructure	• Undertake research into climatic impacts under local conditions.
Financial	• Budget constraints on initiatives to implement adaptation responses	• Emphasis cost neutral responses

8. CONCLUSIONS

The effects of climate change arising from the enhanced greenhouse effect are likely to have an impact on a wide range of human activities. Not the least will be the impact of on the location, design, condition and operation of transport infrastructure. This paper has described a framework for assessing regional risks to transport infrastructure from the effects of climate change and developing adaptation strategies to counteract the likely adverse consequences. The proposed framework can be summarised in terms of the following actions

- identify categories of transport infrastructure relevant to local conditions
- identify the aspects of transport infrastructure and operations that are likely to be affected by climatic factors
- identify climatic variables and their effects on transport infrastructure and operations
- split the region into several sub-regions if there are significant variations in climatic patterns within the region and treat each sub-region separately
- undertake a preliminary risk exposure analysis for each combination of transport infrastructure category and climatic variable
- identify the key climatic variables and transport infrastructure categories for which there is a potentially significant effect and viable response, and drop the other climatic variable and transport infrastructure categories from further analysis
- obtain forecasts that quantify the likely changes in the key climatic variables for the region (and confidence levels for the forecasts, if possible)
- assess the risk severity at a particular time in the future for each combination of transport infrastructure category and key climatic variable
- repeat the risk assessment for each time horizon
- identify the instances of significant to high risk
- select an appropriate response
- implement the response

A likely outcome of a regional risk assessment will be a need to conduct risk assessments for individual items of transport infrastructure in categories assessed to have high risk of adverse effects of climate change, and to adapt infrastructure planning procedures to incorporate explicit consideration of the possible effects of climate change over the expected life of the infrastructure. The proposed framework described in this paper was designed for risk assessment at a regional level, but the same general principles could be applied to individual items of transport infrastructure.

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