Last updated: 25 October 2011
Economic and Social Commission for
Asia and the pacific

More than Transport Infrastructure
-Designing for climate proofing-

Intern Report

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UNESCAP, Bangkok

United Nations
ESCAP

August-October, 2011

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ESCAP Intern Paper

Transport Division

More than Transport Infrastructure -Designing for climate proofing-

Prepared by Rubel Das*

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Abstract

In 2004, the transport sector produced 6.3 Giga-ton CO_2 emissions and road transport accounts for 74% of total transport CO_2 emission. The existing and expected amount of green house gas emission will result unavoidable climate change. Transport is not only for providing support in normal situation, but also for critical situation. The need of transport infrastructure is felt severely in emergency time.

Even though, vulnerability of transport system is difficult to measure due to climate science model limitation and system itself, suitable measure are required to adopt and to confront without knowing full magnitude of expected change. Asia/pacific zone are vulnerable due to geographical situation and social and economic structure. The potential adaptation, response and mitigation are identified in this report. The possible adaptation are Future proof design, Retro-fit solution, Develop contingency plan, Update operating procedure, Research, Integrated Infrastructure system, Behavioral adaptation. Asia/Pacific zone are required also to be prepared for emergency situation by strengthening critical infrastructure and being prepared for evacuation. The mitigation approaches are Network efficiency, Technology improvement, Green growth, Governmental policy

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1. INTRODUCTION

Intergovernmental Panel on climate change (IPCC) (2007) reported that existing and expected amount of green house gas emission will result unavoidable change in climate. With the change of climate, the basic function of transport system such as, business growth, mobility or disaster response has possibility to be impacted. Some obvious impacts to the transportation systems are traffic disruption due flooding and heavy snow and rains, difficult driving conditions, increase in maintenance requirement to the pavement due to high temperature and more frequent icing–thawing phenomenon, overflow of side drains and cross drainage works, submerged bridges due to floods induced by intense precipitation, inundation of coastal roads due to sea level rise, and road blocks due to landslides (Regmi et al. 2009).

Transport infrastructure is not only for providing support in normal situation, but also for critical situation. The need of transport infrastructure is felt severely in emergency time. There is evidence that natural disaster is increasing smoothly in past decades. Figure 1 adopted from EMDAT.BE shows that the total number of disaster is increasing every year from since disaster data base are recorded. When a major disaster strikes a society, if local emergency services are overwhelmed by the consequence, help is requested from the out side of the society. The service from outside world can not reach victims if transport infrastructure is limited or disrupted by the natural event.

However, transport service for emergency response is neglected in Asia/Pacific region, even though this region is the most vulnerable for natural disaster. This region has 60% of total world's population and contributes to 25% of the global domestic product. It encompasses the greatest economic and political diversity. Rapid growth in large regional economies such as China and India has made positions as economic giant. While Many of the countries within Asia/ pacific are developing nation, still struggling to tap into the global economic market.

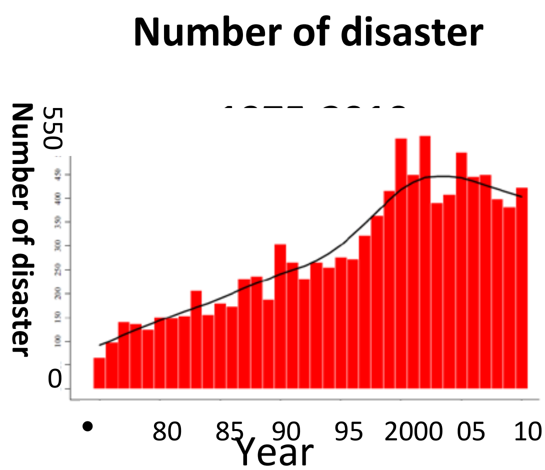

Fig 1: total number of disaster (source:emdat.be)

In summary, Asia/Pacific region is in position of combating with increasing trend of overall amount of greenhouse gas and preparing for emergency response. It is equally important to adapt with the change environment and, get preparation for tackling the unexpected event generated from natural or man-made cause. This study has identified the research gap in transport sector of potential measure for changed environment. It has also highlighted the suitable adaptation and mitigation scope for transport sector to the response of climate change. It is also identified that there is no existing study that focus on prioritizing transport infrastructure for emergency support.

Though climate change is inevitable, it will impact differentially in different parts of the world in different ways. In this context: this research will address the following research questions: How differentially the climate change will be felt in world wide? How to identify the impact of climate change on transport sector? What are the most vulnerable components of transports systems due to climate change? What are the factors that making the transport system vulnerable? What are the potential adaptation, mitigation, and response approaches for Asia?

The reminder of this report is organized as follows. Section 2 presents the climate change trend world wide with closer view for Asia/Pacific region. Section 3 explores the ways of measuring impact of climate change on transport system and impact of different meteorological events on the components of transportation system. Section 4 shows the factors that make the transportation systems vulnerable to climate changes. Section 5 summaries the adaptation, response and mitigation approaches for changed environment. The report ends with drawing conclusions in section 6 based on findings of this research.

2. CLIMATE CHANGE TREND

Climate change is almost invariably considered an issue of global interest even though the extant of climate change is still debated issue. The main consequence of climate change as predicted by most of the existing climate models are an increase in global temperatures, changes in precipitation patterns, and sea level rise. In general climate models predict that increases in temperature will be higher over land areas than over oceans and seas, higher in interiors of continents than in coastal area, and higher when going from the tropics to the polar region in northern hemisphere (IPCC, 2007). The potential consequence of climate change for precipitation patterns are more complex, and depends largely on continental geometry (vicinity of water) but also on the vicinity and shape of mountains and on wind flow direction. In general the existing climate models predict that precipitation will increase in areas adjacent to the polar Regions, and will decrease in areas adjacent to the tropics. Furthermore, tropical precipitation is expected to increase especially during the rainy seasons. The following reports the predicted effects of climate change for various regions across the globe as predicted by a recent IPCC study **(**Christensen et al. (2007)**)**

Africa:

- Nearly 1.5 times global mean increase in temperature
- Dryer the Mediterranean and southern Africa, increasing rainfall in East Africa
- Large uncertainty with respect to precipitation and with respect to change in spatial distribution and frequency of tropical cyclones

Europe:

- Slightly higher increase in mean and temperatures than global mean

- Warming in northern Europe largest in winter, for the Mediterranean largest in summer
- Lowest winter temperatures increase more than average temperatures in northern Europe
- Mean precipitation increase in northern Europe and decrease in most of the Mediterranean area
- Extremes in precipitation very likely to increase in northern Europe
- Increase in risk of summer drought in central Europe and Mediterranean
- Changes in wind strength uncertain, although it is more likely that average and extreme wind speeds will increase.
- Duration of snow season and snow depth very likely to decrease

Asia:

- Increase in temperature higher than global mean
- Summer heat spells will be longer, more intense, and more frequent in East Asia
- Most of Asia will experience an increase in precipitation, either during summer or winter
- Increase in frequency of intense precipitation events in parts of south Asia and in East Asia
- Extreme rainfall and winds due to tropical cyclones likely increase in East Southeast and South Asia

North America:

- Slightly higher increase in temperature than global mean
- Warming largest during winter in northern regions and largest during summer in southwest
- Mean precipitation likely increase in Canada and northeast USA, and likely decrease in southwest USA
- Snow season and snow depth very likely decrease in most of North America

Central and south America:

- Mean increase in temperature by and large similar to global average
- Precipitation likely to decrease in central America
- Large local variation in precipitation in mountainous areas
- Large uncertainly with respect to annual and seasonal mean rainfall in northern south America

Australia and New Zealand:

- Mean increase in temperature by and large similar to global average
- Increased frequency of extreme high daily temperatures, and decrease in the frequency of cold extremes
- Precipitation likely to decrease in southern Australia in winter and spring, likewise for southwest Australia in winter
- Change in rainfall uncertain in northern and central Australia, although extremes are very likely to increase
- Precipitation likely to increase in the west of the South Island of New Zealand
- Increased risk of drought in southern areas of Australia

Polar Regions:

- Mean warming very likely exceeds global mean, and is largest in winter and smallest in summer
- Arctic precipitation increases, likely more in winter than in summer

- Arctic sea ice likely to decrease in extent and thickness (uncertain how Arctic Ocean circulation will change)
- Antarctic temperature and precipitation are likely to increase
- Uncertainty with respect to frequency of extreme temperature and rainfall events in polar region

We have observed wide variation of climate change in world wide. We present, here after, a closer look of climate change trend on Asia/pacific zone. This research is concentrated on Asia/Pacific perspective where 60% of total world's population resides with greatest cultural, economical and ecological diversity. A broad range of climatological and geographic feature exist within the Asia/Pacific region, from temperate areas with marked temperature difference from one season to another, to tropical areas with temperature that are consistently relatively high throughout the year. Generally, the Asia/Pacific region has experienced a warming trend in recent decades consistent with global temperature trends and a changed rainfall pattern. For example, annual average rainfall has declined in the coastal margins and arid plains of Pakistan, the east coast of India and in Indonesia. Yet, rainfall has increased in western and southeast coastal China, Bangladesh, and the Philippines (IPCC, 2007). Climate modeling indicates temperature increases in the Asia/Pacific region on the order of 0.5-2^0 C by 2030 and 1-7^0 C by 2070. This Asia/Pacific region will be affected by a rise in global sea level of approximately 3-16 cm by 2030 an 7-50 cm by 2070 in conjunction with regional sea level variability. Low lying river deltas of Bangladesh, India, Vietnam and China are in greater risk from coastal area inundation due to sea level rise.

Tropical Asia is routinely affected by climate extremes, particularly floods, drought, and cyclones. This zone is characterized by the most densely populated cities in the world and the rural agriculture based economy. In this zone, Vietnam has been observed warming of 0.32^0C in last three decades, while Sri Lanka and tropical India have increased by approximately 0.3^0C and 0.68^0C, respectively (Rupkumat et al, 1994 and 1996). Vast areas of some Tropical Asia nations are prone to flooding including 3.1 million hectares of Bangladesh and million hectares of India (Karl et al, 1995)

3. EFFECT OF CLIMATE CHANGE ON TRANSPORT

Along this century and beyond, climate change will result in a broad range of consequence for most regions of the world including the Asia/Pacific regions. Although, climate change impact assess has been an active area of research for last decades, literature that focus on transport infrastructure is limited, if any. It is quite reasonable as transport infrastructure constructs for long time (e.g. rail infrastructure design for 100 years) and impact of climate change on transport infrastructure is not readily available.

Transportation community – the planners, engineers, builders, operators, and stewards of Nation's roads, airports, rail, transit systems, and ports – are being concerned on the impact of climate change on transport infrastructure. However, it is not easy to measure the direct or indirect impact of climate change on transport infrastructure. There are several ways to examine the influence of climate change on transport. One possible way would be to compare transport systems between regions with very different climate conditions, for example by comparing transport in Spain with transport in Norway. Differences in performance of road, rail and waterway transport system give an indication of the potential impact of climate change. Another approach to analyze the influence of climate would be to consider seasonal variations in transport and travel behavior. Variation of performance of transport systems between seasons can be partly explained by weather variations. For freight transport, variations in demand will be related to seasonal cycles in some sectors, such as the agricultural sector. A third way to address climate issues would be to consider the instantaneous relationship between weather and travel behavior.

Regardless of measurement system variability, some impact of climate change readily observable without measuring the degree of impact for climate change, as set out below:

●Roads: storm surge; prolonged rainfall, flood, drought, snow, extreme wind, frost, fog, soil shrinkage

●Pedestrian road : snow

●Cycle path: flood

●Surface rail: storm surge, prolonged rainfall, flood, snow, extreme wind, prolonged high temperature, humidity

●Underground rail: prolonged rainfall, high temperature

●Airport: electric storm, flood, drought, snow, extreme wind, fog

●Airways: electric storm, extreme wind

●Terminal: drought

●Coastal infrastructure: sea level rise, storm surge, flood, fog

●Sea ports: sea level rise, storm surge, flood, fog, drought

●Inland waterway: storm surge, prolonged rainfall, flood, drought, frost, soil shrinkage

●Embankments: water table rise, storm surge, prolonged rainfall, flood

●Tunnel: flood

●Bridge: storm surge, prolonged rainfall, flood, change in wind direction and scour pattern

●Pipeline: prolonged rainfall, flood

●Control system: storm surge, prolonged rainfall

●GPS: electric storm

●Oil distribution: sea level rise, storm surge, flood

●Gas distribution: sea level rise, storm surge, flood distribution

●Electric car recharge network: electric storm, prolonged rainfall, flood

●CO_2 transport: flood

Highway is one import part of transport system and extremely exposed to weather related variability. The following section explores the impact of climate change on highway operation and infrastructure.

3.1. Effect of temperature:

Small changes in average temperatures will not greatly affect highway systems; however, by the end of the century some regions are projected to experience significant warming that will affect highway planning, construction, and operations. Following provides a summary of how changes in temperature may affect highway infrastructure and operations (**NRC (2008)**).

a) Increases in very hot days and heat waves

- Increased thermal expansion of bridge joints and paved surfaces, causing possible degradation
- Concerns regarding pavement integrity, traffic-related rutting and migration of liquid asphalt, greater need for maintenance of roads and pavement
- Maintenance and construction costs for roads and bridges; stress on bridge integrity due to temperature expansion of concrete joints, steel, asphalt, protective cladding, coats, and sealants
- Asphalt degradation, resulting in possible short-term loss of public access or increased congestion of sections of road and highway during repair and replacement
- Limits on periods of construction activity, and more night time work
- Vehicle overheating and tire degradation

b) Decreases in very cold days

- Regional changes in snow and ice removal costs, environmental impacts from salt and chemical use
- Changes in pavement designs
- Fewer cold-related restrictions for maintenance workers

c) Later onset of seasonal freeze and earlier onset of seasonal thaw

- Changes in seasonal weight restrictions
- Changes in seasonal fuel requirements
- Improved mobility and safety associated with a reduction in winter weather
- Longer construction season in colder areas

3.2. Effect of precipitation change

Increased rains can cause disruptions in the use of highways (mainly due to flooding), as well as structural damage. In some areas, however, drought conditions are expected to increase, which can introduce other threats to the highway system. Following provides a summary of how changes in severe storm intensity may affect highway infrastructure and operations (**NRC (2008)**).

a) Increases in intense precipitation events

- Increases in weather-related delays and traffic disruptions
- Increased flooding of evacuation routes
- Increases in flooding of roadways and tunnels
- Increases in road washout, landslides, and mudslides that damage roadways
- Drainage systems likely to be overloaded more frequently and severely, causing backups and street flooding
- Areas where flooding is already common will face more frequent and severe problems

- If soil moisture levels become too high, structural integrity of roads, bridges, and tunnels (especially where they are already under stress) could be compromised
- Standing water may have adverse effects on road base
- Increased peak stream flow could affect scour rates and influence the size requirement for bridges and culverts

b) Increases in drought conditions

- Increased susceptibility to wildfires, causing road closures due to fire threat or reduced visibility
- Increased risk of mudslides in areas deforested by wildfires

c) Changes in seasonal precipitation and stream flow patterns

- Benefits for safety and reduced interruptions if frozen precipitation shifts to rainfall
- Increased risk of floods, landslides, gradual failures and damage to roads if precipitation changes from snow to rain in winter and spring thaws
- Increased variation in wet/dry spells and decrease in available moisture may cause road foundations to degrade
- Degradation, failure, and replacement of road structures due to increases in ground and foundation movement, shrinkage and changes in groundwater
- Increased maintenance and replacement costs of road infrastructure
- Short-term loss of public access or increased congestion to sections of road and highway
- Changes in access to floodplains during construction season and mobilization periods
- Changes in wetland location and the associated natural protective services that wetlands offer to infrastructure

d) Increases in coastal storm intensity (leading to higher storm surges/wave heights, increased flooding, stronger winds)

- More frequent and potentially more extensive emergency evacuations
- More debris on roads, interrupting travel and shipping
- Bridges, signs, overhead cables and other tall structures are at risk from increased wind speeds
- Increased storm surge and wave impacts on bridge structures
- Decreased expected lifetime of highways exposed to storm surge
- Risk of immediate flooding, damage caused by force of water, and secondary damage caused by collisions with debris
- Erosion of land supporting coastal infrastructure and coastal highways
- Damage to signs, lighting fixtures, and supports
- Reduced drainage rate of low-lying land after rainfall and flooding events
- Damage to infrastructure caused by the loss of coastal wetlands and barrier islands

3.3. Effect of sea level rise:

Rising sea levels can permanently inundate coastal roads and cause damaging erosion. Higher sea levels can exacerbate the effects of storm surge, causing storm surges to reach greater heights and further inland, possibly inflicting additional damages on structures. Following provides a summary of how changes in sea-level rise may affect highway infrastructure and operations (**NRC (2008)**)

a) Rising sea levels (exacerbating effect of higher storm surge, increased salinity of rivers and estuaries, flooding)

- Exposes more areas to effects of storm surge/wave action, causing more frequent interruptions to coastal and low-lying roadway travel
- Amplifies effect of storm surge, causing more severe storm surges requiring evacuation
- Permanent inundation of roads or low-lying feeder roads in coastal areas. Reduces route options/redundancy
- More frequent or severe flooding of underground tunnels and low-lying infrastructure, requiring increased pumping activity
- As the sea-level rises, the coastline will change and highways that were not previously at risk to storm surge and wave damage may be exposed in the future
- Erosion of road base and bridge supports/scour
- Highway embankments at risk of subsidence/heave
- Reduced clearance (including freeboard) under bridges
- Increased maintenance and replacement costs of tunnel infrastructure

Dasgupta et al. (2007) use data from various sources to analyze the impact of 1 to 5 meter sea level rise on 84 developing countries around the globe. Although they do not explicitly assess the impact on transport and transport infrastructure, they do analyze the amount of urban area affected. The average amount of urban area affected for the 84 countries is 1.02% for a 1 meter sea level rise (4.68% for a 5 meter sea level rise). The cost associated with infrastructure damages by future sea level rise, storm surge and flooding can be substantial. Moreover, extreme cases such as SIDR, NARGIS may become frequent and may have even larger impact in the future because of an increased sea level. In a study by Jacob et al. (2007), assuming a 1 meter global sea level rise, the annualized costs of infrastructure damages due to flooding incidences for the metropolitan East Coast in the US are estimated to increase by a factor 3. This implies that costs will increase from approximately 0.5 billion US dollar per year in 2000 to 1.5 billion US Dollar per in year 2100. In the cost calculation it is accounted the indirect cost of network disruption like costs due to delay, detours and trip cancellation etc.

4. VULNERABILITY FACTORS FOR TRANSPORT SYSTEM

The latest edition of the Oxford Dictionary of English gives the following definition of "vulnerable":

"Exposed to the possibility of being attacked or harmed, either physically or emotionally",

It follows from the definition that vulnerability is a relative property: it is vulnerability to something.

The IPCC Third Assessment Report described vulnerability as "a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity". It defined vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes".

Following the similar trend for Transport systems, It can be stated that transport systems are vulnerable to climate change due to three main factors; exposure, susceptibility and resilience.

A) **Exposure**: Exposure can be understood as the values that are present at the location where climate change effects such as floods, cyclone etc can occur. Exposure is defined as the predisposition of a system to be disrupted by a climate change event due to its location in the same area of influence. Exposure is the degree to which a system comes into contact with climate conditions or specific climate impacts (CIG 2007), and the probability, or likelihood, that this stress will affect transportation infrastructure (CCSP 2008). It is important to remember that highway structures are already being exposed to many climate- or weather-related stressors. Climate change can exacerbate (or lessen) these same stressors.

B) Susceptibility: Susceptibility relates to system characteristics. Wind velocity affects the serviceability of structure and generates waves that affect coastal structures. Temperature affects the expansion and contraction of component materials. Rainfall affects water and power supplies, flood protection and drainage infrastructure. Soil moisture affects the serviceability of foundation and slope stability. Sea level rise will affect coastal infrastructure. Susceptibility depends on the strength and integrity of key facilities of system. So infrastructure susceptibility depends on awareness and preparation for expected effect of climate change. Susceptibility is defined as the elements exposed within the system, which influence the probabilities of being harmed at times of hazardous events.

C) Resilience: "The capability of the system to 'return to normal' after having been disturbed"; taking account of both the "maximum disturbance from which the system can recover" and the "speed of recovery". (Berdica, 2002) There are some elements of a resilient transport system Property Description which has been described below (Godschalk (2003) and Murray-Tuite (2006).

Adaptability Can the transport system adapt to climate change?

Autonomy The components of the transport system are able to operate independently so that the failure of one component does not cause others to fail.

Diversity The transport system contains a number of different mode and route choices which ensures that the system does not fail when one component fails.

Mobility Travelers are able to reach their chosen destinations at an acceptable level of service.

Recovery The transport system has the ability to recover quickly to an acceptable level of service with minimal outside assistance after an incident occurs.

Safety The transport system does not harm its users or expose them unduly to hazards.

Strength The transport system's ability to withstand an incident (e.g. a how extreme a flood event can the system cope with?).

The three factors of vulnerability of transport system can be formulated by following equation

$$V = E + S - R \quad \text{…………………..} \ (1)$$

Legend:	
V=Vulnerability;	E= Exposure
S=susceptibility;	R= Resilience

Estimating exposure is the primary step for vulnerability measurement and it is the most ambiguous. Climate science can not confirm the local level effect of climate change, though global level effect can predict with less uncertainty. It is said that the precision of reduced-scale climate analyses is improving, but variability even within regions (such as local elevation change) generates further difficulty of different climate scenarios (USCCP). In spite of methodological limitation, the recent Transportation Research Board (TRB) climate change report suggests "transportation professionals will have to confront and adapt to climate change without knowing the full magnitude of expected change" (UPCC).

Once the types and probabilities of weather events are established with reasonable certainty, measuring the vulnerability of transport infrastructure can begin. However, It is important to formulate policy to protect the infrastructure from long term and acute affects of climate change, and developing new infrastructure system fit for changing climate condition on the basis of available information. Suitable Policy and engineering efforts can increase the resilience and decrease the vulnerability of transport system.

5. MEASURES

The extent to which transport system is vulnerable depends on their exposure to climate change effects and on the ability of impacted system to adapt. Adaptation is the only response available for the impacts that will occur over the next several decades before mitigation measures can have an effect." (Stern Review: The Economics of Climate Change).

There are four main reasons why adaptation is necessary and immediate.

a) Mitigation takes time to work: The global atmosphere is a large system with considerable "lag" built in between changes in levels of emissions to atmosphere and changes in the composition of the atmosphere. The emissions that have been released through the last 150 years and particularly in the latter 20th Century, mean that regionally as well as globally, some change in climate is unavoidable over the next 30 to 40 years.

b) Adaptation will be cheaper now than later: The effects of future climate change will lead to economic consequences. Measures to adapt to these consequences incur costs, but will result in benefits by reducing the residual cost of climate change.

c) Planned adaptation is more effective than last minute, reactive adaptation: Failure to plan can result in unexpected costs relating to travel and business disruption, reduced productivity and costs of repairing or replacing damaged assets. Small businesses take on average 50 days to recover from a flood.

d) Decisions we make now will contribute to our future vulnerability: If current planning activities are not adequately considering the future impacts of climate change, we may be exposing ourselves to greater risk in the future.

However, there is little expectation that adaptation or mitigation alone can avoid climate change impacts. They can complement each other and can significantly reduce the risks of climate change. Herewith, it is also obvious to response on the changed environment.

5.1. Adaptation

Adaptive capacity is the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change. Adaptation is adjustment in ecological, social and economic system in response to actual or expected climatic stimuli and their effect or impacts. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extreme. It involves adjustment to reduce the vulnerability of communities, regions, or activities to climatic change and variability. In this way, enhancements of adaptive capacity reduce vulnerability and promote sustainable development (Smit et al, 2000). However, adoption actions should be flexible and evidence based. Addition to it, adoption measures need to be effective, cost-effective and efficient. Some adoption approach for transport system and infrastructure are described below:

a) Future proof design: Climate change events likely to affect the transport infrastructure are already experienced elsewhere in world. Therefore there is advantage in learning from others. The international Union of Railways (UIC) has matched various global locations in terms of current and projected climate, to enable lesson to be learned. The United Kingdom’s Highway agency has already adopted French temperature standards road surface. USA adopted to increase the clearance for bridges (Meyer, 2008). However, Asia is still has lacking of adopting future proof design policy. Bangladesh, Vietnam, Pacific island countries and flat plains would mostly affected by storm and flood. Transport infrastructure in coastal zone of these countries is required to make robust against failure. One possible strategy is to raise embankments (Tanner et al, 2007). The most obvious consequence of climate change is temperature increase which impact binding capacity of road surface material. Improved surface material such as ‘super pave’ is a potential adaptation technique for climate change in Asia.

b) Retro-fit solution: Given the long life span of the majority of transport infrastructure, it will be critically important to identify and implement cost-effective retro-fitting existing network components. Some major infrastructure may require significant investment to meet adaptation requirement, e.g. coastal rail tracks which cannot be moved and may require complex and costly adaptation. New infrastructure will need to be built consistently with adaptation requirements. In this process, it is required of identification and prioritization of critical network elements for immediate attention and reinforcement.

c) Develop contingency plan: pre planned response for when/if climate change risk are realized so immediate can be managed. Contingency planning needs to be undertaken with the combination of engineering based approaches and awareness of transport user (i.e. educating the public). Installment of additional warning information boards and signs, strengthening of coastal protection are required. Another approach of contingency plan is to have redundant road. Redundant road can increase the resilient to face extreme hazardous events.

d) Update operating procedure: it is required to update the operating procedure to take account of the impact of climate change. Amendment to design standards and operating practice are required in different items such as Drainage system, Earthworks, Redesigning culverts in embankments can help to prevent landslips etc. Besides, due to extreme climate change the frequency of maintenance activities are required to be increased.

e) Research: research to identify vulnerabilities of different transport sectors, determine probable risks identify adaptation options or reduce uncertainty to determining prepared adaptation.

f) Integrated Infrastructure system: Extreme events highlights the interdependence in infrastructure as they are liable to ‘cascade failure’, where the failure of one aspect of infrastructure, such as ‘flood defense’ (i.e. embankment) can lead to other failures, the flooded road disconnect the communication with hospital. Failure in energy sector will interrupt the transport system. Managing national infrastructure is a system issue, requiring collaboration, planning and sharing information between sectors. Resilience is thus required in all sectors to protect against cascade failure and to adapt the infrastructure against the slowly changing climate over the longer term. The infrastructure system requires joined up management with Government, with long term planning for adapting and maintaining infrastructure, and a regulatory and policy framework which provide the platform of integrated improvement of all sectors.

g. Behavioral adaptation: Behavioral aspect has highly potential to adopt with climate change impact. It includes all stakeholders in transport sector. Environment friendly distribution system can be encouraged for example shipment can be delayed until a sufficient load factor is reached. Painting bus roof white can reduce the risk of overheating. Degrading service frequency might be useful adaptation technique in some circumstances. Buses in India and China tend to be more fuel-efficient than those in the industrialized world, primarily because they have considerably smaller engines and lack air conditioning (Sperling and Salon, 2002).

Adaptation policy is a complex issue as there are also regulatory, business and social aspects of adaptation. There is an issue of justification whether extra cost for improving resilience is worth for reducing the risk of failure.

5.2. Response

Climate change may also open new route for transport system. For example, seaways and inland waterways in northern latitudes will be open for more of the year and a continuation of the recent rate of summer ice-melt in the Arctic could open a 'Northern Sea Route' (NSR) between the pacific and Atlantic Oceans. The NSR route between Yokohama and Rotterdam is approximately 4300 km (39%) shorter than the route via Suez Canal. Besides economical benefit through opening new freight route, climate change force people to make evacuation during climatological situation. Transportation is important factor for emergency evacuations. Transport agencies are responsible for providing facilities for evacuees. The potential response for evacuation has been documented in table 1 (Houston 2006). One of the important roles of transportation during evacuation is the direction and control of highway networks.

Table 1 Role of transportation for evacuation

Phase of evacuation	Transportation role
Before (Readiness and activation)	1. Provide road inspection and assessment 2. provide evacuation route 3. Develop control strategy
During (Operation)	1. Order and provide traffic operation resources 2. Direct and control highway network
After (Reentry)	1. Remove debris 2. Restore traffic

Transportation is not the only responsible for providing facilities for evacuation of people during emergency situation. First responders such as police, fire department, and emergency medical service can also facilitate evacuation especially for those who need special needs. Coordination between emergency manager and transportation personnel should work together to determine evacuation routes, and other stakeholders need to be involved to make sure that those routes are clear before evacuation.

When hazards turn into disaster, transportation will be affected the most. It is required to restore the critical transport infrastructure as early basis. Although there is no universal definition of critical transport infrastructure, it is generally said that those transport facilities whose absence from service would significantly affect disaster victims' recovery. Similar concept involves "transportation lifelines", transportation facilities providing essential accesses for emergency services to disaster sites. The examples of critical transport infrastructure are

- Major arterial highways and bridges forming national highway
- International marine harbor, airport, including depots, terminals and stations
- Transportation control systems

5.3. Mitigation

Climate change may be unavoidable, but the magnitude of change is certainly alterable. The policy maker now has the chance to revise some of its transport policy goals and programs in its response to climate change. The most significant effort to reduce greenhouse gas emission is Kyoto protocol which set the target for reduction of greenhouse gas emission compare to 1990. However, some rising giant like china were excluded from this concrete reduction target. Those countries were considered developing country during the signing of Kyoto protocol in 1997. Besides economic growth in this region, social structure is also changing. Asia is facing monumental migration from rural to urban area. By 2030, the percentage of Chinese, India, and Indonesia citizens living in cities will reach 60 percent, 40 percent and 69 percent respectively. In wealthier nations such as Japan and South Korea, the proportion of urban dealer will approach 90 percent (Benjamin, 2011).

Both Economic growth and social growth are contributing to increasing green house gas emission. Acknowledging this situation, some initiative has been taken for green house gas reduction. South Korea plan to reduce carbon di-oxide and other heat trapping gases by 4 percent below 2005 levels by 2020. Japan makes target for 25 percent reduction of green house gas emission from 1990 levels by 2020. Jakarta pledges to cut greenhouse gas emissions 30 percent from 2009 to 2020. New Delhi plans to be a carbon neutral city by 2030 (Benjamin, 2011).

Transportation, as a greater source of carbon di-oxide emission, is a big source to fulfill country target. Figure 2 illustrates the impact of policy for mitigation. Business as usual scenario continues to increase the impact on environment. Mitigation policy will reduce the impact on environment.

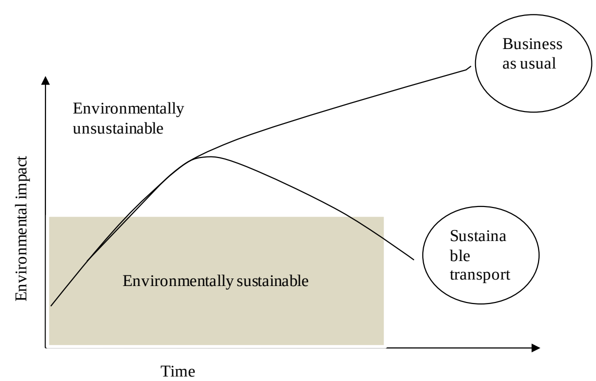

Figure 2: impact of mitigation (based on OECD, 2000)

There are four general strategies available to mitigate green house gases: improved transportation efficiency, lower carbon intensity of fuels, reduce VMT, and enact various governmental policies and program.

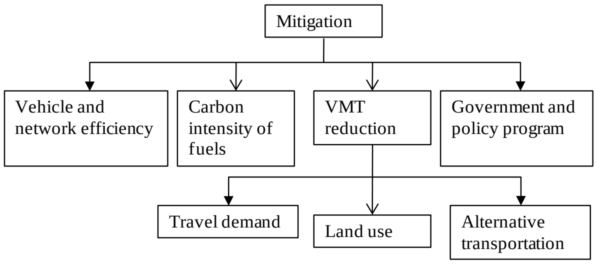

Figure 3 General strategies for greenhouse gas mitigation (Schmidt, 2008)

Some possible step for implementing those strategies describe below.

a. Network efficiency: in 2004, the transport sector produced 6.3 Giga-ton CO_2 emissions and road transport accounts for 74% of total transport CO_2 emission. The enormous waterways in Asia may make a contribution to sustainable transport by allowing road freight transport to shift to inland navigation. However, such modal shift is only economically fair, environmental just and environmentally sound if the draining of wetlands and dredging of rivers comes to an end. What is needed is an intermodal transport system that integrates environmental aspects by using existing capacities more efficiently. Such integrated mobility management has to be accompanied by a fairer charging of infrastructure use that ends with the hidden subsidies for unsustainable transport modes.

There is no doubt that transport activity will continue to grow at a rapid pace for the foreseeable future. Personal motor vehicles consume much more energy and emit far more GHGs per passenger-km than other surface passenger modes. And the number of cars (and light trucks) continues to increase virtually with the prosperity of economy and migration to urban. Growth in GHG emissions can be reduced by restraining the growth in personal vehicle ownership. Such a strategy can, however, only be successful if high levels of mobility and accessibility can be provided by alternative means. The challenge is to improve public transport systems in order to preserve or augment the market share of low-emitting modes. If public transport gets more passengers, it is possible to increase the frequency of departures, which in turn may attract new passengers (Akerman and Hojer, 2006).

b. Technology improvement: Fuel efficient technology innovation is a big step for adaptation with changed environment. This holds, among others, for hydrogen fuel cell, advanced bio-fuel conversion, and improved batteries for electric and hybrid vehicles. Table 2 demonstrates the differences in bus emissions per fuel type, represented by tailpipe emission only.

Table 2 Bus emission per fuel type (CNTM, 2003)

Fuel type	Bus emission (lb CO2/mile)
Gasoline	16.1
Petroleum diesel	13.3
Compressed natural gas	11.7
B20 (20% Biodiesel, 80% diesel)	11.5

Ethanol from corn	11.0
Hydrogen from corn	7.3
B100 (100% Biodiesel)	3.7
Hydrogen from electrolysis	1.3

c. Green growth: Vehicle-miles traveled hold a positive relationship with the magnitude of transport-related carbon emissions because greenhouse gas is a byproduct a vehicle's internal combustion engine. In other words, the more one drives the more one contributes to climate change. The Asian transport policy of integrating transport growth and economic growth is required to revise. It needs to promote spatial patterns that allow for a less transport intensive production, distribution and consumption of goods. It must ensure the use of cleaner fuels and the progressive reduction of transport emissions by forcing the right kind of technology.

Demand management is an efficient mitigation approach. Transport demand is a derived demand. Extra trip and unnecessary trip can be cut by incorporation of demand management strategy. One potential scope for trip demand management is inclusion of e-service. Though on-line shopping has mixed effect on trip demand, freight service can be consolidated by e-service.

d. Governmental policy: The final general mitigations strategy is the enactment and enforcement of various governmental policies and programs that attempt to lower greenhouse gas emissions. According to the European Council of Ministers, government policies or programs are often the most cost-effective mitigation strategies available (ECMT, 2006). Some possible policy are reform of vehicle taxation, fuel tax and emission trading etc.

6. CONCLUSION

This study has attempted to fill gap that has identified in literature on the impact of climate change on transport sector which is gaining more interest due to its importance in economical, social sector and overall integrated infrastructure systems. There is still much to be done. The earth will not see the similar impact generated from climate change in world wide. Due to vast low lying coastal area, the tropical Asia/Pacific region will face the harsh impact from climate change. The potential impacts of climate change in terms of changes in temperature and precipitation averages and extremes on the continental Asia/Pacific territory serves to elucidate the necessity of actions to face the upcoming hard time. However, the impact of climate change on transport infrastructure/system is not easy to observe. It is possible to learn from other country where weather differs or to observe transport performance in same country in different weather condition. As the infrastructure systems are exposed to different and more extreme condition, it is highly likely that degradation and interruption of vital services will occur at certain times. Some components of transport are critical, which can be bottleneck in restoration or response action. Therefore there is need to limit the consequence of failure and accelerate restoration capabilities, both through engineering solutions and by managing consumer expectations. This study summary the potential adaptation, response and mitigation approach for Asia/Pacific zone based on literature review. Here, it is worth to note that there are few literature available which focus on climate change and consequence on transport in Asia/Pacific. Asia/Pacific has the greatest variation on geographic, economic and social customs in the world which gives the both opportunity and disadvantage simultaneously. The opportunity is that Asia/pacific zone can learn climate change effect from neighbor country within this zone. On the other hand, each country is required country specific research for strategy on the ground of climate change.

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