Impact of Climate Change on Transportation Planning

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Abstract: Climate change has become a global and environmental issue in the early 21st century. All natural, human, and transportation infrastructure systems are affected by the climate change. Several issues related to the climate change have been widely discussed, such as transportation planning, environmental protection, energy conservation and reduction of GHG (the emission of vehicular greenhouse gases) emission. Currently, the considerations of climate change are not fully incorporated within the transportation planning process in Taiwan. This paper proposes a conceptual framework of transportation planning process under climate change in Taiwan. The impact of precipitations on urban areas in an operational level is studied through a simulation-based model, DynaTAIWAN. The impact is measured in terms of average travel time, average travel distance, and average stopped time. Numerical experiments are conducted based on a sub-network of Kaohsiung City and different precipitation events are simulated.

Key Words: climate change, flooding, transportation planning

1. INTRODUCTION

In 2005, the U.S was hit by several hurricanes, including: Hurricane Katrina and Hurricane Rita. Hurricane Katrina hit the Gulf Coast in August 29, 2005, and it led to several damages, like: infrastructure damage, flooding, fires, and many people were isolated for days (Litman, 2006). In 2009, Taiwan was hit by Typhoon Morakot, and it caused a serious flooding. The economic loss was near to 20 billion NT dollars. It was a serious disaster in recent years in Taiwan. The typhoon disrupted the public transport networks, knocked down several motorcyclists. The lands cracked, bridges and roads collapsed, walls fell, and the flooding caused mudflows and landslides. There were almost 700 people buried alive and died.

Climate change has become a global and environmental issue in the early 21st century (IPPC, 2007a). In this new climate regime, all natural, human, and transportation infrastructure systems are affected by the climate change (IPPC, 2007b). The impacts would vary from mode to mode of transportation and region to region of country (Plumeau and Lawe, 2009).
There will be negative and severe impact on economic growth due to the lack of efficient and reliable transportation system. (Crafts and Leunig, 2005).

All of the transportation systems would be affected by the climate change, and the impacts include: increased numbers of hot days and hot waves, the gradual warming of ambient temperatures in polar areas, seasonal changes, sea level change, increased heavy precipitation, and increased numbers of tropical storms (Jaroszewske et al., 2010). The issue of climate change should be incorporated within the transportation planning process, including the planning, design, construction, operation and maintenance. Some researchers have tried to incorporate the impact of climate change into the transportation planning process in policies. (Schmidt and Meyer, 2009).

This paper aims at proposing a conceptual framework of transportation planning process under climate change in Taiwan. The framework outlines some guidelines for considering possible disasters in transportation planning procedure. The interrelationship between precipitation and transportation infrastructure is examined based on historical data from Central Weather Bureau (CWB) and Directorate General of Highways (DGH). The impact of precipitations on urban areas in an operational level is simulated and studied through a simulation-assignment model, DynaTAIWAN. The impact is measured in terms of average travel time, average travel distance, and average stopped time.

Next section presents a brief review of related researches. A conceptual framework and some recommendations of transportation planning under climate change in Taiwan are presented in Section 3. Typhoon Morakot and the flood disaster are described in Section 4. Numerical experiments based on different precipitation events in a sub-network of Kaohsiung City are discussed in Section 5, follow by the brief summary.

2. LITERATURE REVIEW

Several topics related to climate change are reviewed. Researches based on climate change are classified into 4 categories, including: climate change in transportation planning, the impact of adverse weather on transportation, reduction of GHG emission in transportation, and hurricane evacuation, and they are briefly reviewed and described as follow.

2.1 Climate Change in Transportation Planning

In order to understand the relationship between climate change and transportation planning, some applications of planning models and simulation software under climate change are described below:

Suarez et al. (2005) showed the operation of the surface transportation system is influenced by the climate change in the Boston Metro Area. The Urban Transportation Modelling System (UTMS), a conventional analytical tool, was used to simulate the traffic flows in an urban network. The results show that trips during a flood might reduce because the origin/destination locations and/or surface streets are flooded.

Schmidt and Meyer (2009) thought that the inclusion of climate change in the transport planning process is important due to the CO2 and vehicle miles traveled (VMT), thus the consideration can help transportation planners to develop the most cost effective strategies. A
conceptual framework and some recommendations for transportation planning were presented to show how to consider climate change in the process.

Meyer et al. (2010) examined asset management systems in climate change. The asset management systems considered uncertainty and make investment decisions. The primary criteria used to assess vulnerabilities in asset management systems included: uncertainty, rate of climate change, extent of disruption and severity of disruption.

Figliozzi et al. (2010) described that climate change would produce heavy precipitations. The impacts of urban flooding on transportation are quantified and analyzed based on cost data. The results indicated that any cost analysis is sensitive to delay costs. A classification of flooding costs, preventative measures, and short-term and long-term recommendations are presented.

2.2 The Impact of Adverse Weather on Transportation

Climate change causes the happening of adverse weather and adverse weather deteriorates the traffic conditions and influences traffic parameters, such as: traffic flow, speed, density, travel time, delay. Several researches have discussed the relationship between adverse weather and the traffic parameters, and they are reviewed below:

Jaroszweski et al. (2010) indicated adaptation was an important plan of the climate change policy. With over 20% of accidents were associated with the effects of meteorology (Edwards, 1999). The climate change will have influences on all modes of transportation, including: increased numbers of hot days, decreased numbers of cold days, increased heavy precipitation, seasonal changes, drought, sea level change and extreme events.

Watkins and Hallenbeck (2010) focused on the results of the analysis of the impact of weather on freeway travel times in greater Seattle. The data includes: WSDOT loop sensor volume data, National Oceanic and Atmospheric Administration (NOAA) weather data, and average travel times from loop detectors. Percent of congested days and 80th and 95th percentile travel times were calculated and compared under rain and no rain conditions. The results showed adverse conditions would not cause significant changes in travel time when the traffic volume is low. The rain would increase the travel time slightly when the freeway is already congested. During the beginning of a peak period, rain increased travel time significantly and caused congestion.

Gallivan et al. (2009) investigated that climate change had the possibility to produce more frequent and intense precipitation events. This paper proposed a comprehensive classification of flooding costs, and short-term and long-term recommendations. Despite cooperating with counties and local transportation agencies, the estimation of costs associated with flooding events was difficult due to the lack of complete and systematic records. The possibility of death and personal injuries should be included in future research efforts and cost effectiveness analysis.

Tu et al. (2007) found that in terms of travel time variability, adverse weather could make travel time less reliable. Edwards (1999) found adverse weather caused significant reduction in mean speed.

2.3 Reduction of GHG Emission in Transportation
GHG emission is one of the factors that contribute to climate change. Many countries have treated GHG emission reduction as their goal in transportation planning (Schmidt and Meyer, 2009).

Bartholomew and Ewing (2008) addressed that the transportation sector had become the largest source of CO2 emissions in the U.S. This research quantified CO2 and provided important guidance for the development of GHG reduction strategies to meet current and emerging policies.

Aaron and Jason (2010) pointed out the transportation sector was a leading cause of GHG emissions. They proposed strategies to reduce these emissions, which included the promotion of alternative fuel vehicles, improved public transportation, transit-oriented development (TOD), and various pricing strategies. A series of evidence which showed the unequal vulnerabilities, responsibilities, benefits and costs from climate change and climate change policies are reviewed.

Hanna et al. (2008) used CLIMATE-C to assess climate impact assessment on transportation and the economy in Canada. It linked transportation and economy. It was handled through a random based multi-regional input-output model (RUBMRIO). The RUBMRIO model accounted for both (1) economic linkages between the different sectors of the economy and (2) transportation shipping cost. The results of simulation test indicated that the model was sensitive to weather changing. The sensitive analysis showed that with the increase of the frequency of critical weather conditions, the service performance of transportation system would lower.

2.4 Hurricane Evacuation

Several types of natural disasters, including hurricane, typhoon, heavy precipitations and flooding, occur more and more frequently. The emergency management and evacuation operations are more and more important in recent years.

Litman (2006) examined failures in hurricane Katrina and Rita emergency responses. For hurricane Katrina, the people who depended on public transit were not well evacuated. For hurricane Rita, people who excessively relied on automobiles resulted in traffic congestion and fuel shortages. Suitable emergency responses required to consider the needs of vulnerable residents. Improved emergency responses planning can efficiently enhance the use of resources.

In summary, climate change considerations are not incorporated into the transportation planning process in Taiwan. It is necessary to incorporate climate change considerations into the planning process as it can help transportation planners to develop the most cost effective strategies. The adverse weather increases the travel time, cause congestion, and reduce the number of trips. Suitable emergency response planning should consider the use of resources efficiently. Several planning methods and simulation models are applied to simulate the negative impact of climate change. Several indices are used to evaluate the performance of strategies. How to apply these models under climate change is still a critical issue and so far there is no conclusive evidence to demonstrate the best planning and simulation models for transportation planning.
3. TRANSPORTATION PLANNING UNDER CLIMATE CHANGE IN TAIWAN

This section describes the conceptual framework of transportation planning process under climate change in Taiwan. Traditional transportation planning considers the impact of transportation projects on social and economic aspects; however, several important issues, such as the design, maintenance, environmental and risk evaluation, GHG emission and infrastructure under climate change, are neglected in the process. A conceptual framework which incorporates climate change factors is illustrated in Figure 1. Important components, including problem definition, vision, goal, method, data, project development and possible applications, evaluation and relative policy and strategy, are described hereafter.

Figure 1 Conceptual framework of transportation planning under climate change in Taiwan

1. Impact of climate change in Taiwan
Typhoons and heavy precipitations are the major natural disasters in Taiwan. In long-term planning, the heavy precipitations, temperature variations, water levels, wind loads, wave heights, and flooding should be taken into considerations in transportation planning. The design standards of the infrastructure should be considered for long-term operation and maintenance. The environmental and risk evaluations should be implemented to develop strategies for the responses of climate change and risks. In medium term planning, the data should be gathered from CWB, DGH and relative organizations, such as: Water Resources Agency (WRA). In short-term planning, operation and evacuations are the most important tasks. The warning messages associated with climate change should be announced to people when there is a natural disaster. A suitable evacuation planning needs to be developed for metropolitan applications.

2. Vision
Vision is an initial step in the transportation planning process. The adaptation of climate change should be included in the vision to enhance the importance, and such vision might vary from one location to another. The major vision could include quality of life, quality of environment, prosperity, safety assurance, and quality of transportation.

3. Goal
Goals could vary from city to city in a country (Schmidt and Meyer, 2009). The goals under climate change include incorporate climate change into transportation planning, the percentage of GHG emission reduction, and enhancement of infrastructure. For example, in Rotterdam Netherlands, the goal of transportation planning was to achieve a 50% reduction in CO2 emissions below 1990 levels by 2025. (Rotterdam, Netherlands, 2008). In Taiwan, the goal is to achieve a 45% reduction in CO2 emissions below 2005 levels by 2020.

4. Data
The data is a key component for analysis under climate change considerations. The data include precipitations, infrastructure, traffic counts, density and speed. There are two categories of data associated with climate change, including predictable and unpredictable data. The predictable data include: weather, hydrology, environment and traffic data. The unpredictable data is the extreme evens. The weather data could be gained from CWB, and the traffic data such as speed, flows, and density could be gained from loop detectors.

5. Planning and evaluation method
There are several models and methods for analysis of the transportation planning under climate change. The methods may include long-term planning, medium-term planning, and short-term planning. In long-term planning, several techniques have been proposed. The models include: long-run trend analysis, sketch planning, activity-based models, and full-scale UTMS. The four-step planning processes in UTMS, including trip generation, trip distribution, modal split, and traffic assignment, should be restructured to respond to the climate change. In medium-term planning, medium-run trend analysis, UTMS, disaggregate and aggregate models could be used for analyzing possible impact under different scenarios. In short-term planning, simulation and statistics analysis are two possible methodologies for evaluation. Some new models are developed for evaluating traffic, and the other possible simulation tools include: Mobile6 (Atlanta Regional Commission, ARC), CLIMATE-C (Maoh et al. (2008) and DynaTAIWAN (Hu et al., 2007, 2008).

6. Project development and possible applications
The government should create a prioritization for climate change projects. The projects and applications under climate change should be developed and implemented. The possible applications are ITS technology, evacuation, emergency management, real-time logistics, and route dispatching.

7. Evaluation
The objective of evaluation is to identify which strategy could respond to climate change effectively. The evaluations may include air quality, transportation alternatives and land use evaluation. The infrastructure may damage rapidly under climate change. The major evaluation criteria include travel time, travel distance, stopped time, average speed, $CO_2$ reduction, sustainability of infrastructure (ex: 20 years).

8. Policy and strategy
The relative policies and strategies are set up after the implementation of evaluations. The
possible policies and strategies include policies, operational strategy, design standards of infrastructure, financial strategy and GHG emission reduction strategies.

4. TYPHOON MORAKOT AND THE FLOOD DISASTER

This section describes the flood disaster and the loss caused by Typhoon Morakot. Morakot is the eighth typhoon formed in the West Pacific region in 2009. The statistics from CWB reported changes in precipitation patterns, and data from DGH showed the number of accumulated collapsed roads and bridges. Table 1 shows the relationship between accumulated precipitation and the number of accumulated collapsed roads and bridges. The results indicate that with the increase of accumulated precipitation, the number of accumulated collapsed roads and bridges increase. When the accumulated precipitation is more than 2,400 mm, the number of accumulated collapsed roads and bridges increase dramatically.

<table>
<thead>
<tr>
<th>Date</th>
<th>Accumulated precipitation (mm)</th>
<th>The number of accumulated collapsed roads</th>
<th>The number of accumulated collapsed bridges</th>
<th>Major location of flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/6/2009</td>
<td>322</td>
<td>2</td>
<td>0</td>
<td>Yunlin, Taoyuan</td>
</tr>
<tr>
<td>8/7/2009</td>
<td>504</td>
<td>15</td>
<td>2</td>
<td>Pingtung, Kaohsiung</td>
</tr>
<tr>
<td>8/8/2009</td>
<td>2,407</td>
<td>114</td>
<td>31</td>
<td>Pingtung, Kaohsiung, Chiayi, Taitung</td>
</tr>
<tr>
<td>8/9/2009</td>
<td>2,847</td>
<td>295</td>
<td>96</td>
<td>Kaohsiung</td>
</tr>
<tr>
<td>8/10/2009</td>
<td>3,018</td>
<td>343</td>
<td>99</td>
<td>Chiayi</td>
</tr>
</tbody>
</table>
Figure 2 Curve fit of accumulated precipitation and collapsed roads data. The basic form of exponential regression model is 
\[ Y = b_0 \times (e^{b_1 \times X}) \]. Table 2 reveals the summary of exponential regression model, and it shows 
\( R^2 \) value is 0.983, and adjusted \( R^2 \) value is 0.978. The p-value is 0.001 and less than 0.05. The outcomes are to reject the null hypothesis, which mean there is an evidence of a statistical difference between the two distributions. The equation of the exponential regression model is
\[ \ln(\text{collapsed_roads}) = \ln(0.042 + 0.002 \times \text{rainfall}) \].

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig. (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>.424</td>
<td>.304</td>
<td>1.396</td>
<td>.257</td>
</tr>
<tr>
<td>Precipitation</td>
<td>.002</td>
<td>.000</td>
<td>.992</td>
<td>13.224</td>
</tr>
</tbody>
</table>

\[ R^2 = .983 \]
\[ \text{Adjusted } R^2 = .978 \]

5. NUMERICAL EXPERIMENTS

In this section, in order to include possible climate change in the analysis, a simulation-assignment tool, DynaTAIWAN, is applied to simulate traffic flow distribution under a flood. The network performance is evaluated through some indexes, such as average travel time (ATT), average travel distance (ATD), and average stopped time (AST). Assumptions are summarized as follows:
- Assume the O-D demand is the same throughout the experiments.
There is a flood in an urban area.
The damaged links are generated randomly in the network.

5.1 Data Collection

Three major data sets for numerical experiments, including: the network characteristics, historical O-D flows, accumulated precipitation and collapsed roads data, are described as below:

5.1.1 The Network Configuration

The network in this study area includes 132 nodes, 363 links and 27 traffic zones. There are 21 vehicle detectors available in the network to measure the traffic counts, and they are depicted in Figure 3. The locations of VDs are shown as black dots.

Figure 3 Network configuration and VDs location

5.1.2 Historical O-D Flows

The historical OD flows are critical to the accuracy of time-dependent O-D estimation and prediction, thus a reliable data is required. Original O-D trip tables are obtained based on the project, titled “National Intercity Travel Demand Analysis”. The total number of cars is 84,482 PCU, and the total number of scooters is 33,799 PCU.

5.1.3 Accumulated Precipitation and Collapsed Roads

The accumulated precipitation and collapsed roads data are collected from CWB and DGH. Table 3 shows the accumulated precipitation and collapsed roads in southern Taiwan.
Table 3 Accumulated precipitations and collapsed roads

<table>
<thead>
<tr>
<th>Total kilometer traveled (km) (Chiayi, Tainan, Kaohsiung, Bingdong, Hualian, Taitung)</th>
<th>Accumulated precipitation (mm)</th>
<th>Accumulated collapsed roads (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,701.2</td>
<td>1,000</td>
<td>9.0</td>
</tr>
<tr>
<td>2,000</td>
<td>60.0</td>
<td></td>
</tr>
<tr>
<td>3,000</td>
<td>204.8</td>
<td></td>
</tr>
</tbody>
</table>

Data source: Directorate General of Highways (DGH)

5.2 Simulation Scenarios

Four basic scenarios are designed to observe how the system performance changes under different levels of precipitation and these scenarios are listed in Table 4. There are 363 links in the sub-network of Kaohsiung City network. The number of damaged links is the product of total number of links in the network (363 links) multiples by the percentage of accumulated collapsed roads. In scenario 1, there is no rain. The locations of simulated 9 damaged links are shown in Figure 4, and they are generated randomly.

Table 4 Simulation scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Accumulated precipitation (mm)</th>
<th>The percentage of accumulated collapsed roads (%)</th>
<th>The number of damaged links in the sub-network of Kaohsiung City</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1,000</td>
<td>0.103</td>
<td>1 Link ID (2175→125)</td>
</tr>
<tr>
<td>3</td>
<td>2,000</td>
<td>0.686</td>
<td>3 (2175→125, 5122→126, 6480→2710 )</td>
</tr>
<tr>
<td>4</td>
<td>3,000</td>
<td>2.354</td>
<td>9 (2175→125, 5122→126, 6480→2710, 3045→3150, 3050→2897, 132→6484, 124→128, 130→6483, 2616→2892)</td>
</tr>
</tbody>
</table>
5.3 Results Analysis

5.3.1 Basic Experiments

The simulation results are summarized in Table 5. The results show that with the increase of the accumulated precipitation, ATT, AST, and ATD also increase. The variations of ATT in 4 scenarios are illustrated in Figure 5. The results show that ATT would increase significantly in scenario 3, as the accumulated precipitation is 2,000 mm.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>ATT (min)</th>
<th>ATT Reduction (%)</th>
<th>AST (min)</th>
<th>ATD (m)</th>
<th>ATT (min)</th>
<th>ATT Reduction (%)</th>
<th>AST (min)</th>
<th>ATD (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43.5</td>
<td>1.0</td>
<td>25.4</td>
<td>6,265</td>
<td>32.8</td>
<td>1.0</td>
<td>11.4</td>
<td>5,456</td>
</tr>
<tr>
<td>2</td>
<td>69.6</td>
<td>1.5</td>
<td>45.6</td>
<td>6,423</td>
<td>52.7</td>
<td>1.6</td>
<td>23.1</td>
<td>5,495</td>
</tr>
<tr>
<td>3</td>
<td>98.5</td>
<td>2.7</td>
<td>57.5</td>
<td>6,251</td>
<td>77.6</td>
<td>2.4</td>
<td>31.4</td>
<td>5,386</td>
</tr>
<tr>
<td>4</td>
<td>206.0</td>
<td>4.7</td>
<td>131.1</td>
<td>6,600</td>
<td>163.8</td>
<td>5.0</td>
<td>90.8</td>
<td>5,759</td>
</tr>
</tbody>
</table>
5.3.2 Demand management: the reduction of O-D demand

In order to observe the system performance under various demand levels, several loading factors are tested. The loading factor is defined as the ratio of the total number of cars and scooters generated in the network during the simulation period to a base value of about 84,482 PCU (car) and 33,799 PCU (scooters), and which represents a loading factor of 1.0.

Table 6 is the summary of ATT in different loading factors based on scenario 4 (with accumulated precipitation: 3,000 mm). Loading factors of 0.5 to 1.0 are tested, and the results are delineated in Figure 6 and Table 5. The results show that with decreasing loading factors, ATT decreases, and as the loading factor reaches 0.5, ATT in scenario 4 (with accumulated precipitation: 3,000 mm) is close to ATT in scenario 1 (with no rain). The results indicate that the traffic capacity drops dramatically and O-D demand should be reduced in order to maintain reasonable service.

Table 6 Summary of ATT in different loading factors

<table>
<thead>
<tr>
<th>scenario</th>
<th>loading factors</th>
<th>ATT (min) (passenger car)</th>
<th>ATT (min) (scooter/motorcycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (no rain)</td>
<td>1.0</td>
<td>43.5</td>
<td>32.8</td>
</tr>
<tr>
<td>4 (accumulated</td>
<td>1.0</td>
<td>206.0</td>
<td>163.8</td>
</tr>
<tr>
<td>precipitation:</td>
<td>0.9</td>
<td>146.0</td>
<td>122.7</td>
</tr>
<tr>
<td>3,000 mm)</td>
<td>0.8</td>
<td>120.0</td>
<td>97.8</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>70.7</td>
<td>61.4</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>54.1</td>
<td>38.2</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>45.1</td>
<td>36.9</td>
</tr>
</tbody>
</table>
ATT ratio is \( \frac{\text{ATT (loading factor)}}{\text{ATT (in scenario 1)}} \), and it is defined as ATT of loading factors in scenario 4 divided by ATT in scenario 1 (with no rain). ATT ratio is shown in Figure 7. The slope of the curve in Figure 7 might be a good indicator to illustrate ATT in scenario 4 (with accumulated precipitation 3,000 mm) is about 4.9 times larger than ATT in scenario 1 (with no rain). When the number of vehicles reduces to about 50%, ATT ratio in scenario 4 (with accumulated precipitation 3,000 mm) is close to ATT ratio in scenario 1 (with no rain).

5.3.3 Supply management: provision of real-time information for all travelers

It is obvious that the network capacity drops dramatically due to the heavy precipitations. The provision of real-time information for travelers is also a possible strategy. The results are
illustrated in Table 7. The results show that ATT, AST and ATD reduce when real-time information is provided for travelers in the network. ATT of vehicles with real time information (in scenario 4 (RI)) reduces about 13% compared with ATT of vehicles without real time information (in scenario 4).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Passenger Car</th>
<th>Scooter/Motorcycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ATT (min)</td>
<td>ATT Reduction (%)</td>
</tr>
<tr>
<td>Scenario 4- no info</td>
<td>206.0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>131.1</td>
<td>6,600</td>
</tr>
<tr>
<td></td>
<td>163.8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>90.8</td>
<td>5,759</td>
</tr>
<tr>
<td>Scenario 4- real-time info</td>
<td>180.5</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>116.8</td>
<td>6,410</td>
</tr>
<tr>
<td></td>
<td>144.9</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>76.3</td>
<td>5,519</td>
</tr>
</tbody>
</table>

6. CONCLUSIONS

In this research, a conceptual framework and some recommendations of transportation planning process under climate change in Taiwan are presented. The impact of precipitations on urban areas in an operational level through a simulation-based model DynaTAIWAN is studied.

The interrelationship between accumulated precipitation and transportation infrastructure is examined based on historical data from CWB and DGH. The numerical results indicate that ATT, AST, and ATD also increase with respect to the accumulated precipitation. ATT would increase significantly as the accumulated precipitation is 2,000 mm.

Two possible operational strategies of management are proposed and examined (1) demand management: the reduction of O-D demand and (2) supply management: provision of real-time information for all travelers. The results show positive benefits through these two strategies.

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