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*Article*

# Development of a Prototype Web GIS-Based Disaster Management System for Safe Operation of the Next Generation Bimodal Tram, South Korea—Focused Flooding and Snowfall

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**Abstract:** The Korea Railroad Research Institute (KRRI) has developed a bimodal tram and advanced bus rapid transit (BRT) system which is an optimized public transit system created by mixing the railway's punctual operation and the bus' easy and convenient access. The bimodal tram system provides mass-transportation service with an eco-friendly and human-centered approach. Natural disasters have been increasing worldwide in recent years, including floods, snow, and typhoons disasters. Flooding is the most frequent natural disaster in many countries and is increasingly a concern with climate change; it seriously affects people's lives and productivity, causing considerable economic loss and significant damage. Enhanced conventional disaster management systems are needed to support comprehensive actions to secure safety and convenience. The objective of this study is to develop a prototype version of a Web GIS-based bimodal tram disaster management system (BTDMS) using the Storm Water Management Model (SWMM) 5.0 to enhance on-time operation and safety of the bimodal tram system. The BTDMS was tested at the bimodal tram test railroad by simulating probable maximum flood (PMF) and snow melting for forecasting flooding and snow covered roads. This result could provide the basis for plans to protect against flooding disasters and snow covered roads in operating the bimodal tram system. The BTDMS will be used to assess and predict weather impacts on roadway conditions and operations and thus has the potential to influence economic growth. The methodology presented in this paper makes it possible to manage impacts of flooding and snowfall on urban transportation and enhance operation of the bimodal tram system. Such a methodology based on modeling could be created for most metropolitan areas in Korea and in many other countries.

**Keywords:** bimodal tram; BRT; BTDMS; climate change; flooding and snowfall disasters

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## 1. Introduction

Korea has a small land area (100,210 km$^2$) and one of the highest population densities in the world. The population concentration in Korea has become a serious social problem and had led to an explosive increase in demands for transportation [1]. In order to overcome the limits of surface traffic, the central government, which is supposed to support these costs, recommends more cost-effective railroad systems rather than subway systems, and local governments also prefer various railway systems, because lightweight electric railway systems receive financial support from the central government [2].

Many attempts have been made to overcome limitations in existing transportation in other countries [3]. The Bus Rapid Transit (BRT) system has advantages over others in providing flexibility as well as speed with low cost. The BRT system has been operating in Europe and the United States as well as many other countries because of its lower construction cost compared with other transportation [4]. Transportation speed increases with introduction of bus-only lanes, on-time schedules, and other miscellaneous bus service facilities [5]. The Korea Railroad Research Institute (KRRI) built on this model to develop a bimodal tram system, which is an optimized public transit system that combines the railway's punctual operation and the bus' easy and convenient access. Compared with the BRT system, the bimodal tram system which has recently been developed in Korea is an upgraded transportation system. The bimodal tram system provides mass-transportation service with eco-friendly and human-centered approaches, which may contribute to sustainable development [6,7]. For any sustainable transportation system, safety is an important consideration, and there is considerable interest in ensuring the safety of the bimodal tram system.

Natural disasters have been increasing worldwide in recent years, including floods, snow, and typhoon disasters [8,9]. Flooding is the most frequent natural disaster in China; it seriously affects people's lives and productivity, causing considerable economic loss and serious damage to towns [10]. In recent years, many devastating flood events have occurred in Turkey and Bangladesh, and these floods have caused extensive damage to both public and private property, and costly social disruption for a time after the disaster [11,12]. In the Netherlands, there is increasing attention for environmental changes that affect development in the near future because climate change can lead to an increase in flood risks [13].

In Korea as well as in other countries, climate change has resulted in unexpected high-intensity rainfall events and combined with urban sprawl has been increasing runoff [14–16]. Urban flooding with surcharges in sewer systems has been investigated because of unexpected torrential storm events that caused significant human and economic losses [17,18]. Also, urban flooding affects infrastructure and important lifelines such as transportation, communication, and power lines. So, there are needs to enhance conventional disaster management systems to provide comprehensive actions to secure safety and convenience. Early warning of disasters is important to disaster prevention and risk assessment [19,20], thus, for more efficient operation of the bimodal tram system, disasters resulting from flooding by heavy rainfall or snow melt should be predicted systematically [21–25]. In this study, climate change implies extreme climate events (e.g., unexpected torrential storm events or heavy snowfall) because climate change triggers extreme weather events [26–28]. Also, climate change is considered using historical data and the data used in this study does not include any attempt to account for climate change in the future. Moreover, of various natural disasters, only flooding and snowfall events were considered in this study.

The objective of this study is to develop a prototype version of a Web GIS-based Bimodal Tram Disaster Management System (BTDMS) using the Storm Water Management Model (SWMM) 5.0 [29] to secure on-time operation and safety of the bimodal tram system. Although there are limitations in forecasting and preventing natural disasters, an accurate, integrated urban flooding management system using the SWMM engine and Web technology will be an effective tool in securing safety in operating the bimodal tram system. In addition, the integrated urban flooding management system can be linked with transportation-related disaster management systems in the future.

## 2. Bimodal Tram and Climate Change in Korea

### *2.1. What is the Bimodal Tram System?*

The bimodal tram system (Figure 1) has both the railway's punctual operation and the bus' easy and convenient access. The bimodal tram is a type of guided bus, and uses the Phileas system developed by the Dutch company Advanced Public Transport Systems [30]. Its operation is based on magnetic guidance which relies on magnets buried in the roadway at regular intervals, and the vehicle moves towards the magnets due to magnetic force. In places where magnets are not installed, the vehicle is operated as a conventional bus. Advantages of the bimodal tram system can be briefly described as follows [2]:

(1) Railway's punctuality and the bus' easy and convenient access and flexibility.
(2) Eco-friendly Compressed Natural Gas hybrid propulsion system.
(3) Possible access to the vehicle at the foot level and no need to use a mobile ramp for people with mobility impairments.
(4) Lower cost of construction compared with subway and light rail transit systems.

**Figure 1.** Overview of the bimodal tram system.


## *2.2. Climate Change in Korea*

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted and international negotiations considering climate change originated in the United Nations Conference on Environment & Development in 1992. The Kyoto Protocol, an international agreement linked to the UNFCCC, was agreed to in the 3rd general meeting of UNFCCC, and it has rapidly risen as a global issue [31].

Levels of carbon dioxide in the atmosphere are one of the major sources triggering global warming, and are continuing to rise at an accelerating rate because of the increased use of fossil fuel since the Industrial Revolution [32,33]. According to the climate change scenarios of International Panel on Climate Change (IPCC), even though various attempts have been made to reduce $CO_2$ emissions, the trend of increasing $CO_2$ emissions continues, and $CO_2$ concentration in the atmosphere has been increased by 146% between 1990 and 2010 [34]. Greenhouse Gas (GHG) emissions of Korea were about 488 million tons, which was ranked ninth in the world, and Korea was the country with the highest GHG growth rate (113%) among Organization for Economic Cooperation and Development (OECD) countries from 1990–2007 [35].

Temperature in Korea has increased 1.5 °C during the past century, which is twice the average global temperature increase, creating enhanced conditions for typhoons to form and flourish [36–39]. This has triggered changes in rainfall patterns and increasing trends of torrential rains with unstable atmosphere conditions throughout Korea [22,23,25]. Especially over the past two years, an unprecedented combination of crisis including heavy rainfall and snowstorms has frequently resulted in many human victims and widespread property damage as well as water/snow-clogged roads and highways (Figure 2).

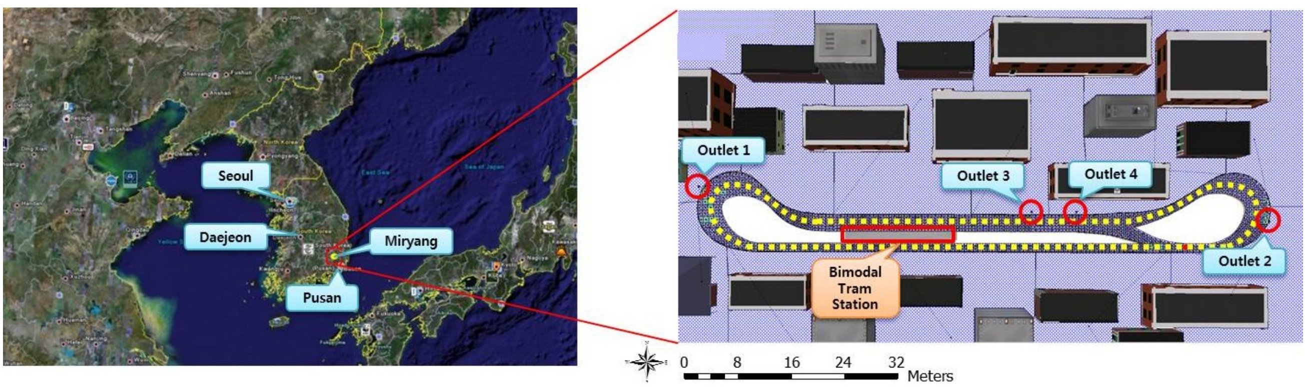
**Figure 2.** Water/snow-clogged roads due to extreme events.

## 3. Development of the BTMDS to Simulate Flooding and Snow Melting

### *3.1. Study Area*

The study area (4000 $m^2$ in size), which is the bimodal tram test railroad located in Miryang, Gyeongsangnam-do, South Korea, was selected to evaluate the applicability of the Web GIS-based BTDMS in forecasting urban flooding and snow melt (Figure 3). The area of the test railroad is made up of both impervious area (*i.e.*, pavement) and pervious area (*i.e.*, grass). The sewer system and field parameters at the study area were used as the SWMM input parameters (*i.e.*, subcatchments, conduits, junctions, and outlets) based on the floor plan of the test railroad provided by Hyundai Engineering. A field survey was also conducted to obtain more details, such as direction of overland flow, of the study area in order to predict flooding and snow melt areas.

**Figure 3.** Location and detailed plan of the study area (test bed) at Miryang, Gyeongsangnam-do in South Korea.



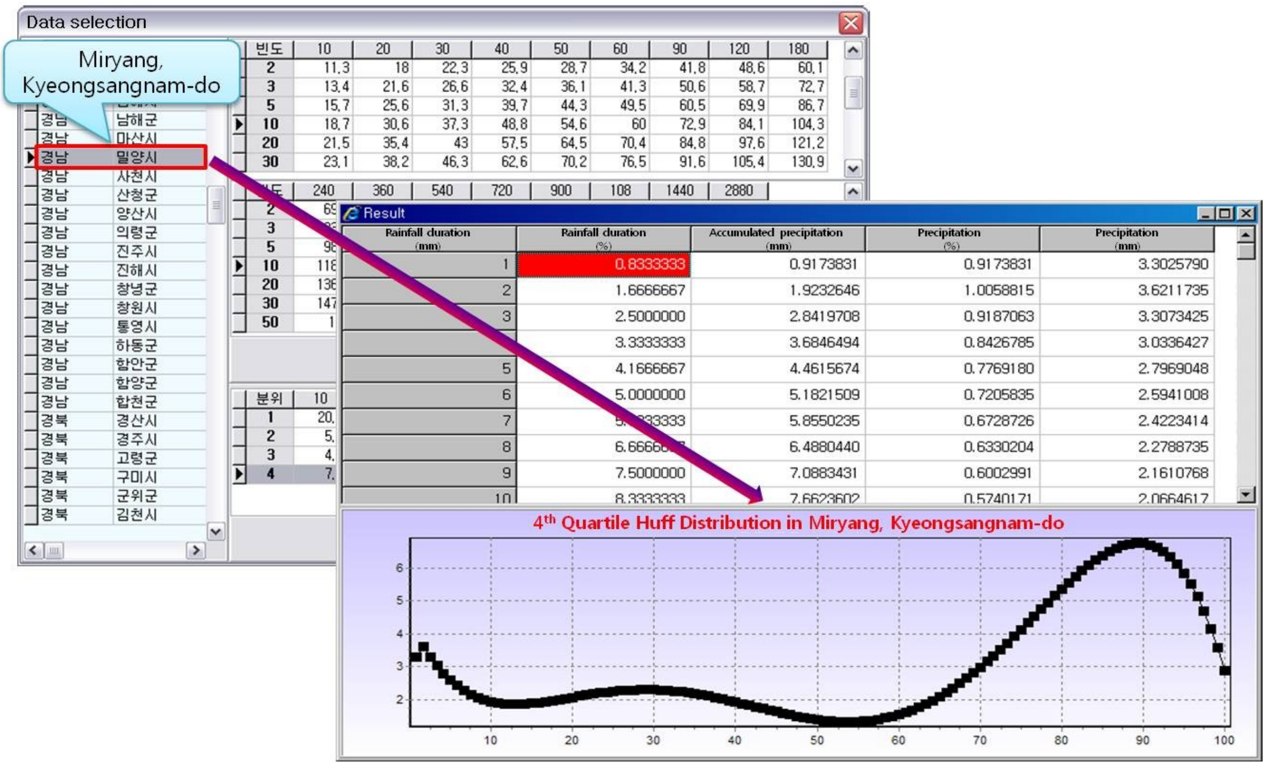
### *3.2. Flood Simulation Module*

A flood simulation module was incorporated with the following developments and analysis. (1) To retrieve and apply rainfall data (*i.e.*, design storm distribution, probability distribution of rainfall events) in the flood simulation module effectively, a design rainfall estimation module using the Huff method [40–42] was developed. (2) An overland flow module was developed to enable the simulation of overland flow for multiple subcatchments, and offer visual simulation results for the flood simulation module in BTDMS. (3) Finally, analysis and setting up a flood warning message were carried out in order to notify users of levels of flooding risk.

#### 3.2.1. Development of Design Rainfall Estimation Module Using Huff Method

To simulate urban flooding using SWMM [43], detailed rainfall distribution data first need to be defined. The design storm distribution was created using the probability distribution of rainfall events for various recurrence intervals and storm durations. To facilitate these processes, the nation-wide probability distribution of rainfall event Web database was created and the interface between the Web database and the modified BTDMS interface was created. Figure 4 shows the design rainfall estimation module interface of BTDMS that was developed. The probability distribution of rainfall event data is stored in the MS SQL DB at the server-side, and the simple interface retrieves the data from the database and then generates design storm data for BTDMS. With the nation-wide database, BTDMS can be easily used at any location in Korea with no additional programming.

**Figure 4.** Design storm estimation module for BTDMS.




BTDMS offers a new method for retrieval of rainfall data and it enables access to current probability rainfall data and user input data, and connects with the Korea Meteorological Administration (KMA) forecasting rainfall data in real time. Also, when user input data and KMA forecasting rainfall data are applied to the Huff module as well as probability rainfall data, the flood simulation module can set the interval in minutes for deriving rainfall distribution. This module can be used in real-time forecasting of urban flooding in operating the bimodal tram system with the KMA forecasting rainfall data at the KMA web site [44].

The BTDMS was developed to prepare for a localized torrential rainfall or heavy downpour by carrying out urban flooding simulation to insure the safe operation of the bimodal tram system. For this system, data of the worst condition for daily rainfall has to be set up. So, Probable Maximum Flood (PMF) was applied to BTDMS after considering flood discharge estimation according to recurrence interval events of rainfall, rainfall duration, and Huff's four-quartile rainfall patterns. When PMF was estimated, probability rainfall was used with 200 year recurrence interval events for durations of 120, 240, 360 min in the study area, Miryang, and each of three duration rainfalls (120, 240, 360 min in 200 year recurrence interval events) was applied to Huff's four-quartile rainfall patterns. Thus, a total of 12 rainfall scenarios were analyzed when simulating PMF. In addition, a batch file was created to automatically calculate PMF. It can analyze PMF by comparing each runoff coming out of the outlet in the tram railroad. The results of this study only consider overflow in the study area (test bed) at Miryang and do not account for any potential inflow from other areas.

### 3.2.2. Development of Overland Flow Module for Spatial-Temporal Visualization Module

The current SWMM module does not allow overland flow for multiple subcatchments. Thus, a new module was developed to enable simulation of overland flow in multiple subcatchments from upper subcatchments for practical simulation of the overland flow in the case of flash flooding. In the current SWMM, overflow coming out of a junction is not routed into neighboring subcatchments. Thus, we developed a new overland flow module, which can route overflow from a saturated junction to neighboring subcatchments at the base of slopes.

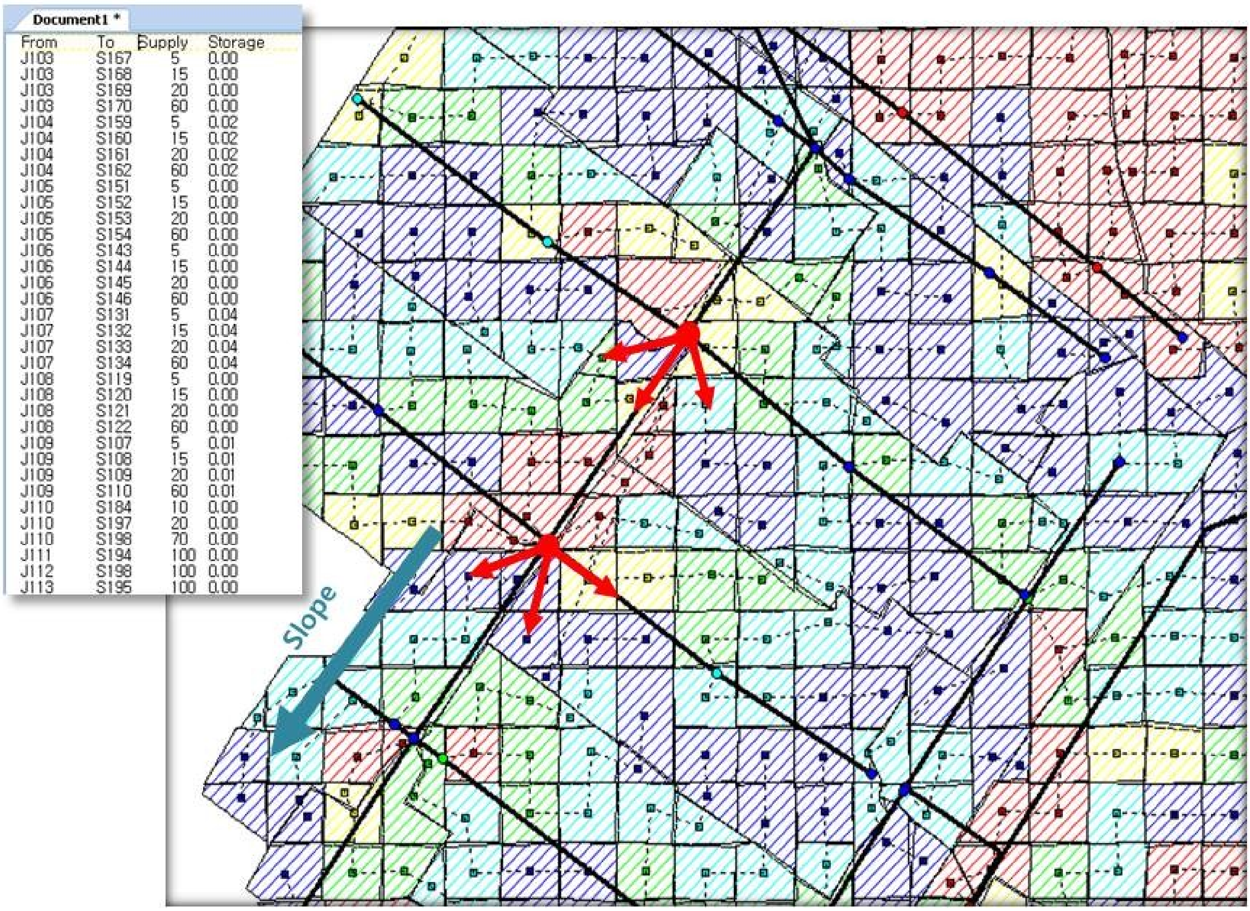
In this study, very detailed subcatchment networks were defined and the flow allocation database was prepared based on slope of the study watershed as shown in Figure 5. In this module, the surface storage of each subcatchment can be defined in the flow allocation database. With these data, the new module can simulate realistic overland flow to secure the safety of the bimodal tram system.

To provide visual simulation results for BTDMS, the SWMM interface was modified, and the runoff depth module was modified and entered into the SWMM engine and interface. The runoff volume was converted into runoff depth by considering the area of each subcatchment.

### 3.2.3. Analysis and Setting up a Flood Warning Message from Rainfall

As flood inundation maps and the real-time location of a tram are displayed on the screen (see Section 3.4 for more details), flooding risk assessment of tram roads based on inundated sections can be analyzed. Flooding risk assessment is analyzed by the degree of flood in a subcatchment. A flood warning is determined depending on how far the tram location is from where flooding occurs. So, defining a distance between the real-time tram location and inundated areas from rainfall is important to analyze flooding risk assessment of tram roads. The tram roads of this study area consist of a number of subcatchments in which flooding or overland flow is simulated. In the BTDMS, the tram locations are assigned in subcatchments on the center of the roads at regular intervals. Thus, the flooding risks are only considered on the center of subcatchments, ignoring flooding in the neighboring subcatchments. Main surface water outlets are placed on the curved sections in the tram design, so the flooding risk on the curved sections is higher than in the straight sections because flooding usually starts from main outlets. In order to overcome the limitation, we grouped the neighboring subcatchments together to evaluate flooding risk effectively. After these processes, the location of the tram and distance from inundated sections to the tram were calculated.

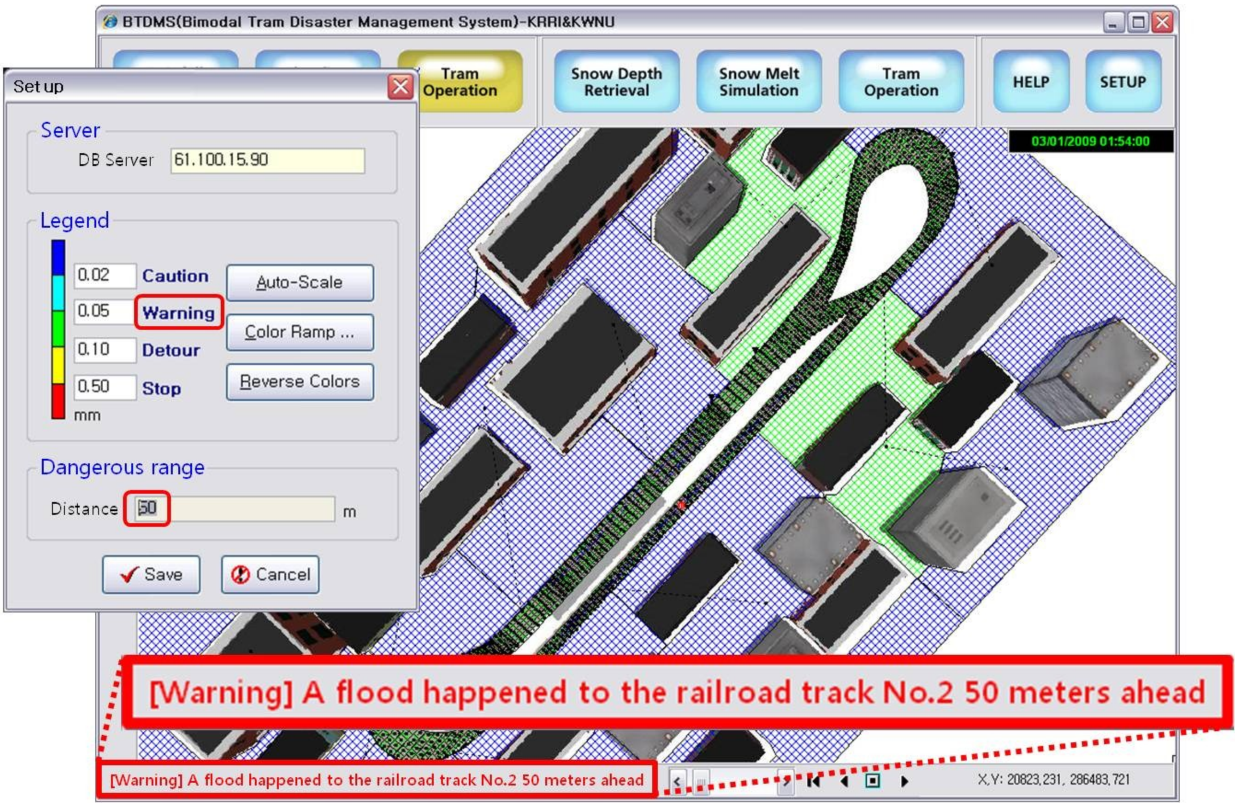
**Figure 5.** Development of overland flow simulation with surcharged flooding data.




The message was set up considering the results of flooding risk assessment of tram roads according to inundated areas. Message types were classified as "Caution, Warning, Detour, Stop" by the runoff depth for each subcatchment inundated from rainfall. Also, the BTDMS interface allowed users to set up minimum distance for which a warning message appears. Figure 6 shows the results of flooding risk assessment and setting up the flood warning message.

However, there are problems in stopping the flooding simulation whenever the message was displayed as levels of flooding risk. In order to compensate in the case of the simulated situation (*i.e.*, Caution, Warning, and Detour), this message was displayed below the interface of BTDMS, and it was able to notify users of levels of flooding risk. If the tram system on the roads comes to a halt because its condition is under flood inundation, the message of "Stop" will be displayed, and it will help decision makers judge whether the tram should stop or not.

**Figure 6.** The result of flooding risk assessment and setting up the message of warning of flash flooding by heavy rainfall.



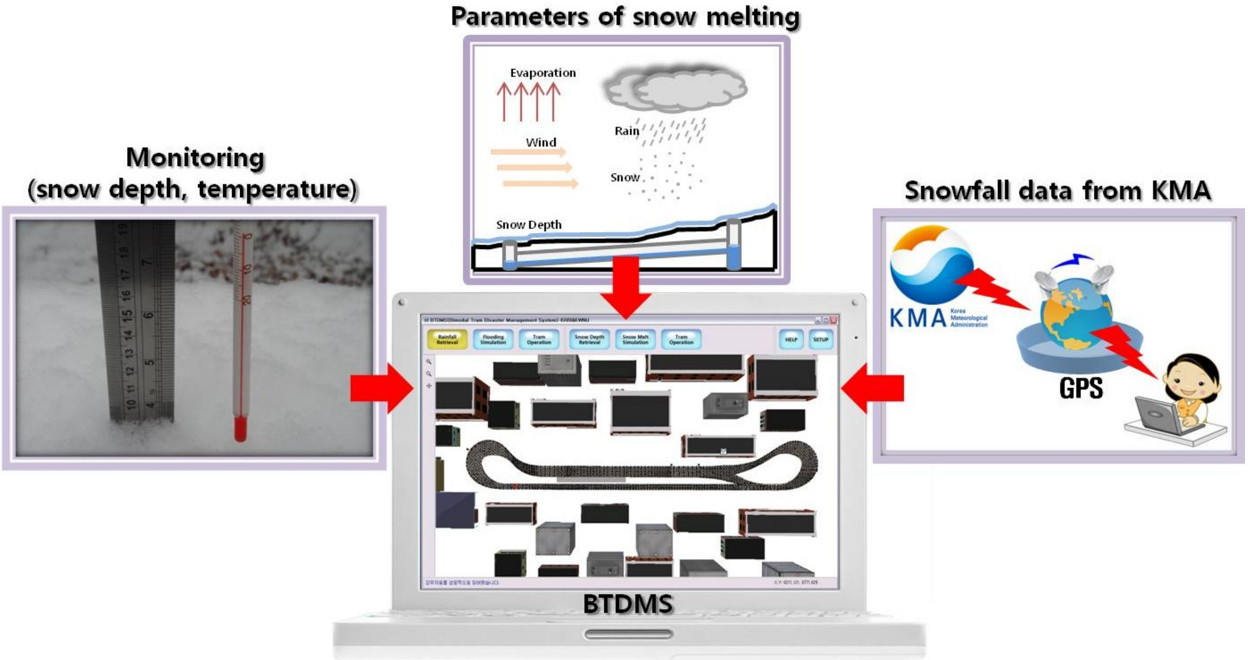

### *3.3. Snow Melting Simulation Module*

A snow melting simulation module was created that uses snowfall (snow depth) data from the KMA web site and that simulates snow melt in sunny spots and shaded areas using a modification of the SWMM engine and input parameters. The snow melting module runs with an initial snow depth (snow accumulation), then it shows the visual process and result of snow melting with time on the tram roads. A network of monitoring locations can be installed in which the bimodal tram system is operated, and BTDMS simulation can be validated with observed data to simulate localized snow melting on the tram roads.

#### 3.3.1. Retrieval of Data of Snowfall (Snow Depth)

When snow melt is simulated, snowfall (snow depth) data are obtained from monitoring and KMA. Users can conveniently predict real-time snow covered roads by using KMA forecast snowfall amounts from the KMA web site. Temperature is one of the most sensitive parameters and can be input hourly by users because temperatures differ in time and space. For more practical estimation and convenient data input, the real-time BTDMS and Global Positioning System (GPS) coordinate system for tram location can be coupled together (Figure 7). For effective BTMDS operation, it really needs a network of monitoring locations in which the bimodal tram system is applied and a network of monitoring locations will be constructed to measure the required real-time information (e.g., initial snow depth, temperature, and wind speed) which will be retrieved from an Oracle database.

**Figure 7.** Retrieval of snowfall data and parameters (e.g., snow depth and temperature) from monitoring and KMA.




3.3.2. Development of the Snow Melting Module in Winter

SWMM which is a core model in the system, BTDMS, has snowpack parameters related to snow melt. When the simulation of snow melt is conducted, parameters for a sunny spot, shade, and intermediate values between a sunny spot and shade have to be set up separately. However, in the current SWMM, application of more than two snowpack parameters is not allowed when simulating snow melt. Some minor problems were verified when the module was applied to pilot study areas, and the current model was not able to allow a site to change from a sunny spot to shade and *vice versa* over time. This flexibility is important in this application, and so a snow melt module was developed by modifying the SWMM engine and interface to reflect the two parameter sets (*i.e.*, parameters of a sunny spot and shade) and their change with time automatically.

The module was applied to BTDMS with snowpack parameters derived from the previous study [45] performed for calibration and verification of input data of SWMM 5.0 through snow melt monitoring on snowy roads in winter. Of the various parameters for a sunny spot and shade when the simulation of snow melting were carried out using SWMM 5.0, temperature parameters were the most sensitive. Because temperature parameters vary temporally and spatially, the interface of the snow melt simulation was built to allow users to input data (temperature change, initial snow depth) into the snow melt module. Intermediate parameters for locations that are intermediate between a sunny and a shady location can be calculated as their arithmetic mean and put into the snow melt module automatically. Moreover, in the snow melt simulation, it presents how snow depth decreases by the time (e.g., sunshine hours) and places (e.g., sunny spots and shaded areas) for drivability. The snow melt water is not connected to flooding simulation in BTDMS.

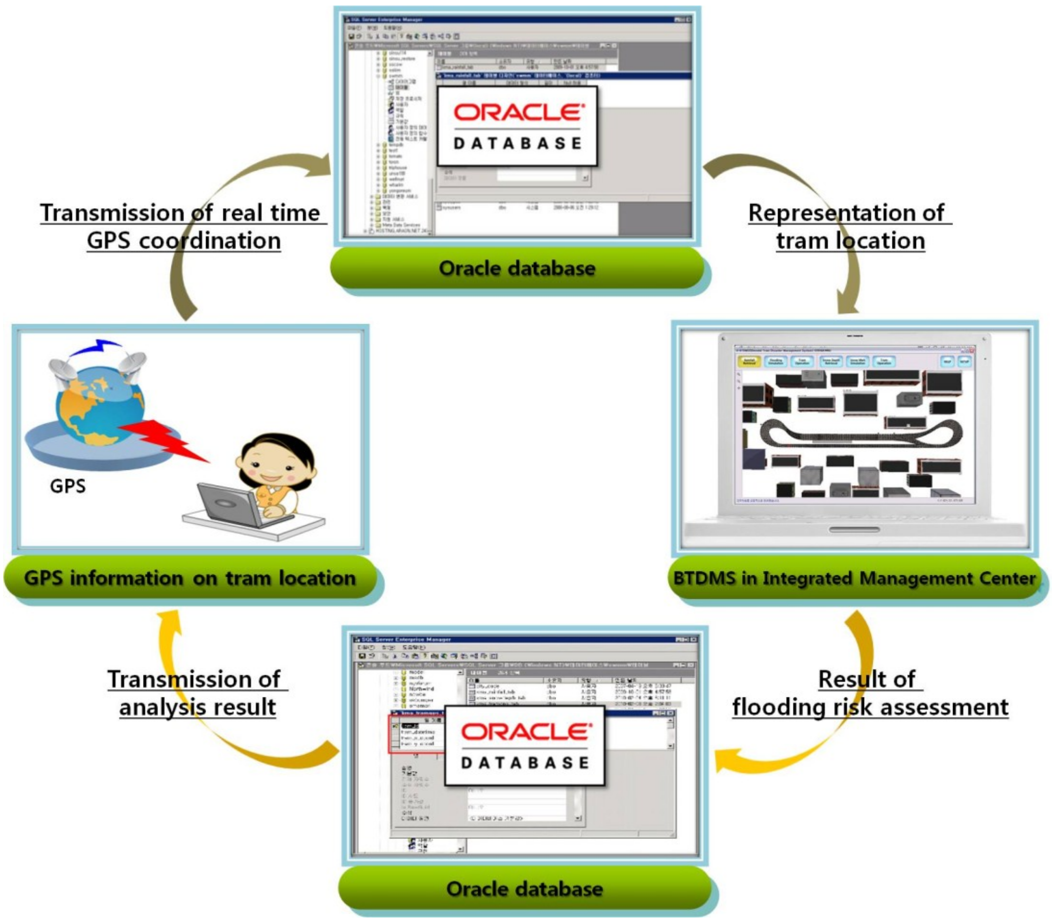
In the pilot study area (Miryang, Gyeongsangnam-do) of the bimodal tram system, the database of monthly sunrise and sunset based on data from Korea Astronomy & Space Science Institute was constructed, and it was applied to the snow melt module of BTDMS. Also, to simulate snow melt accurately, the effect of buildings around the bimodal tram railroad was considered in modeling of sunny spot and shade. Thus, subcatchments were divided and applied to BTDMS considering sunny spot and shade variability for the test railroad over time.

### *3.4. Integration for Effective Interconnection of BTDMS and Bimodal Tram Operating System*

The flood simulation module that models flooding by heavy rainfall and a snow melt module that models roads blocked by extreme snowfall are included in BTDMS. These modules were connected with the bimodal tram operating system in real time, and can predict flooding caused by heavy rainfall and road blockage by deep snow that can help decision makers effectively take care of problems related to flooding when the bimodal tram is operating.

Real-time location information of the bimodal tram is required to assess flooding risk in operating the bimodal tram system. BTDMS and the bimodal tram operating system (tram management system to control real-time tram location and its general information) were integrated to retrieve real-time GPS coordination for tram location. In addition, the system was constructed to be able to transmit the results of flooding risk assessment using a flood simulation module. In order to transmit real-time GPS coordination for tram location and the result of flooding risk assessment, an Oracle Database was utilized. Figure 8 shows an overview of the interconnection of BTDMS and the bimodal tram operating system using Oracle Database.

**Figure 8.** Overview of interconnection of BTDMS and tram operating system.

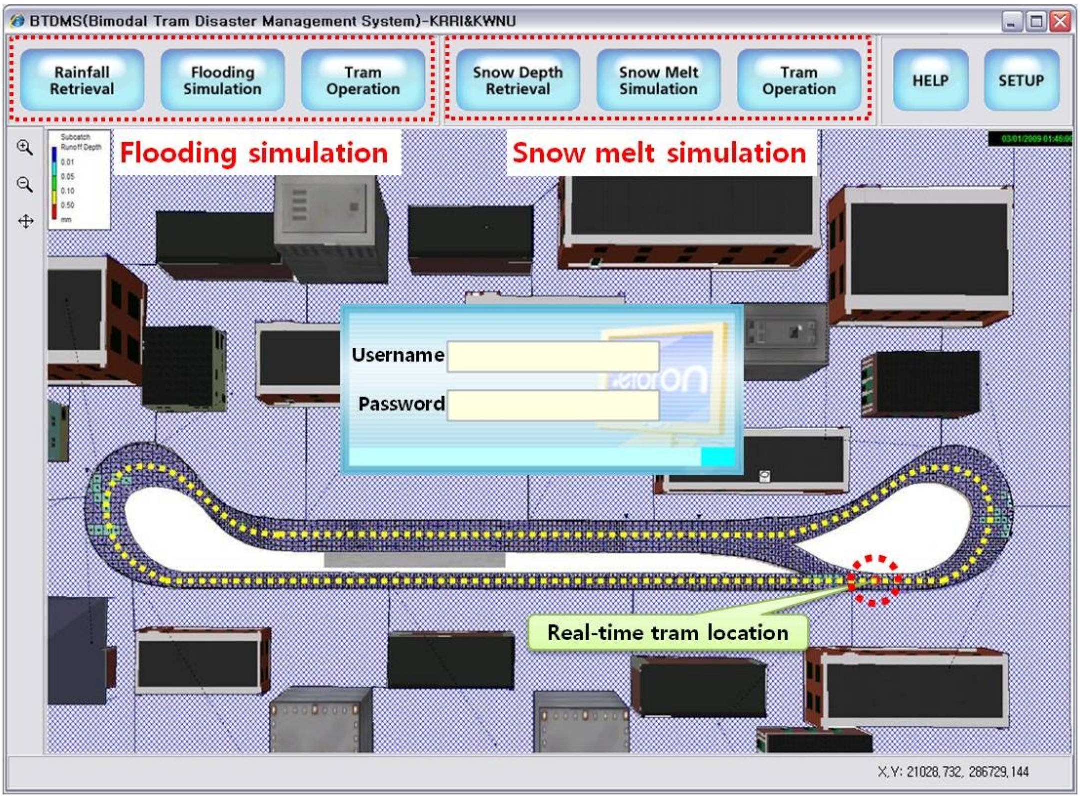


## 4. Results and Discussion

### *4.1. Development of Prototype Version of the Web GIS-Based BTDMS*

For fast and accurate simulation of urban flash flooding to secure the safety of passengers on the bimodal tram, a Web GIS-based BTDMS was developed in this study. Various modules (including a design rainfall estimation module, a flood depth and area estimation module, and a snow melting module) were connected with the Web GIS-based BTDMS. After removing unnecessary functions in SWMM, required functions for the Web GIS-based BTDMS were set up. Most of SWMM functionalities are not needed for the Web GIS-based BTDMS, thus the SWMM interface was modified for simulation of urban flash flooding. In this study, the BTDMS loading module was developed with Active X programming to install BTDMS and perform a general check for stable operation of the system. With this, user authentication is included for safety reasons and regular check-up for a newer version is included. Figure 9 shows the interface of the Web GIS-based BTDMS, developed with Active X programming and modifications in the SWMM engine and interface.

**Figure 9.** Interface of the Web GIS-based BTDMS.




As shown in Figure 9, this system was divided into two simulation parts (flooding simulation/snow melting simulation). Three icons on the upper left of the screen are a section of flooding simulation, and they were integrated with all modules related to flooding simulation already introduced in Section 3.2. The other three icons on the center of the screen are a part of snow melt simulation, and they were consolidated into BTDMS. The snow melting simulation was described in Section 3.3. Because BTDMS and the bimodal tram operating system were interconnected in real time, various data (*i.e.*, weather data, real-time tram location, and data on flooding risk) were able to be linked.

*4.2. Flooding Simulation Using BTDMS*

When simulation of urban flooding is carried out, PMF is estimated with 12 data for probability rainfall to prepare for worst case climate impacts. Figure 10 shows the calculation of PMF for 360-min rainfall duration with a 200-year recurrence interval event in Miryang. In four outlets of the test bed tram railroad, the result of PMF was estimated from 1.78 $m^3$/min to 3.62 $m^3$/min for 360-min rainfall duration in 200-year recurrence interval events and a third quartile Huff distribution (Table 1). This result could help create a plan to protect against a flooding disaster.

**Figure 10.** Calculation of PMF for 360-min rainfall duration in 200-year recurrence interval events in Miryang.

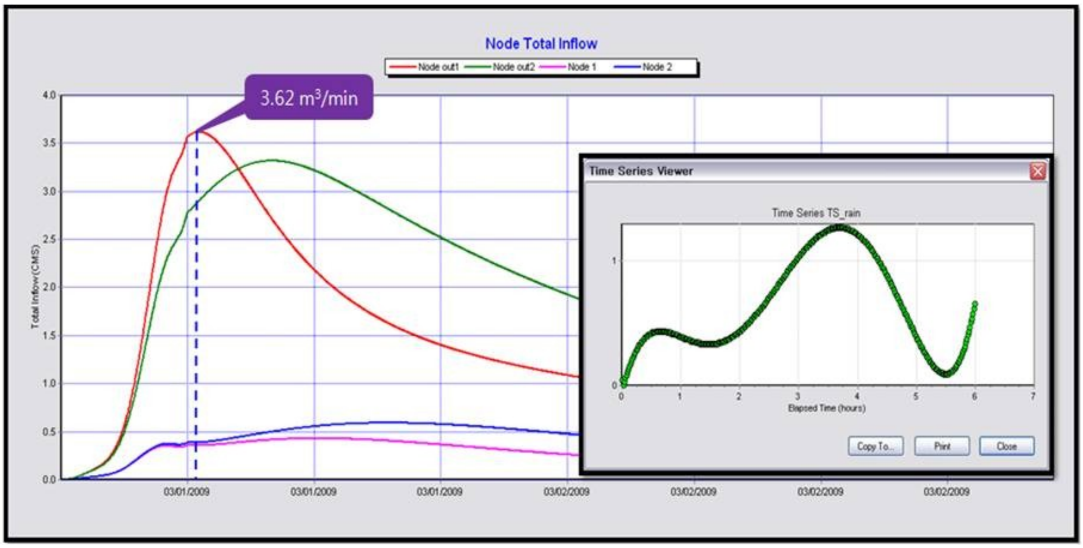



**Table 1.** Results of calculation of PMF for 200-year recurrence interval events in Miryang.

| | | PMF for 200-year recurrence interval events ($m^3$/min) | | | |
|---|---|---|---|---|---|
| | | **First quartile** | **Second quartile** | **Third quartile** | **Fourth quartile** |
| Rainfall | 120 | 1.78 | 1.80 | 1.80 | 1.81 |
| duration | 240 | 2.98 | 3.06 | 3.10 | 3.10 |
| (min) | 360 | 3.29 | 3.53 | 3.62 | 3.59 |

In this study, simulation of urban flooding with BTDMS was conducted prior to flooding risk analysis of the tram operating system and two bimodal trams (Tram ID 1, 2) were simulated with the BTDMS. In the case of Tram ID 1, one minute after simulation of level of flooding risk, the message in the system said "<Caution> flooding happened to the railroad track 50 meters ahead", and after 2 min, it showed the same level of flooding risk as Caution but indicated that the flooding area was being extended (Figure 11).

About 7 min later, tram ID 2 was given a flooding risk level of "Caution", after 14 min BTDMS showed flooding risk level of "Warning" for tram ID 2, and then 50 min later because the urban flooding condition presented a serious situation, it said flooding risk level is "Stop" through the pop-up message box. Thus, results of flooding risk analysis from heavy or steady rainfall with respect to the real-time bimodal tram location with GPS are transmitted to the bimodal tram operating system server to help decision makers decide on any necessary modification in the bimodal tram operations (Figure 12).

**Figure 11.** Results of flood simulation and visualization of tram ID 1.

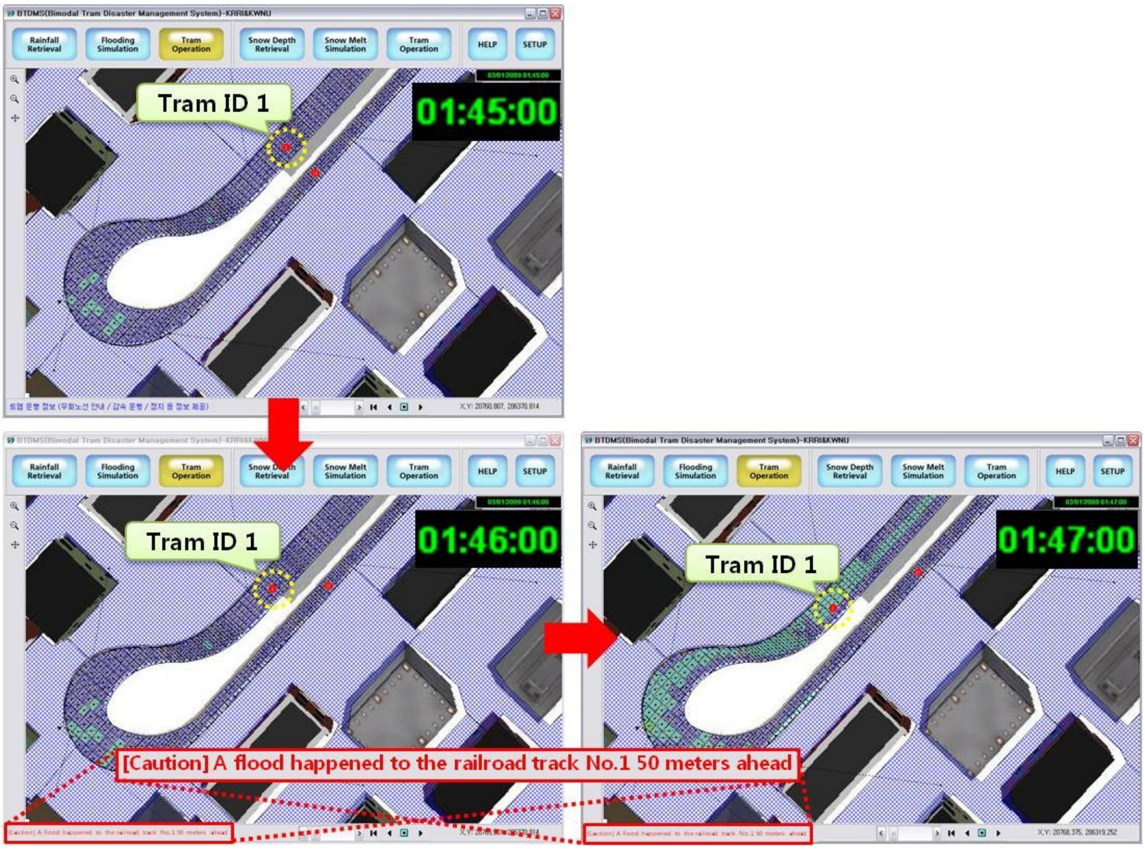
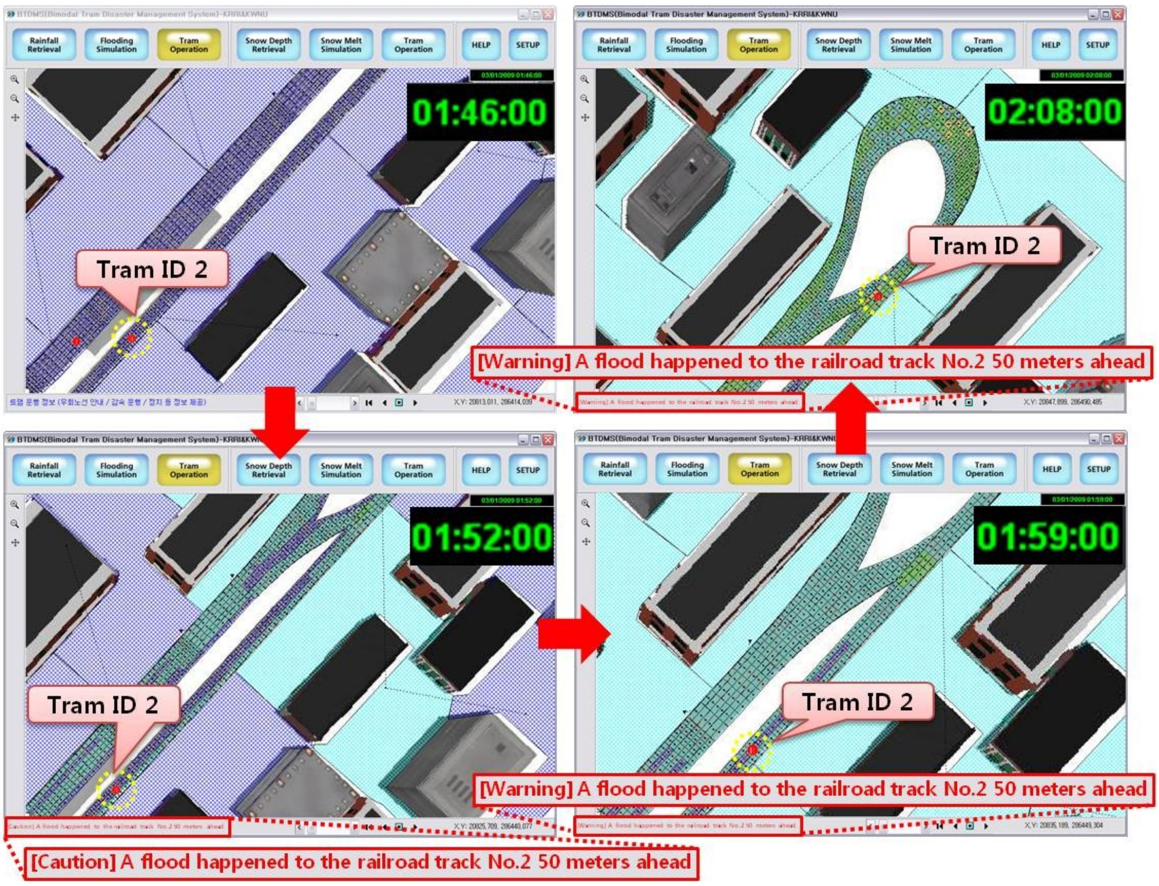


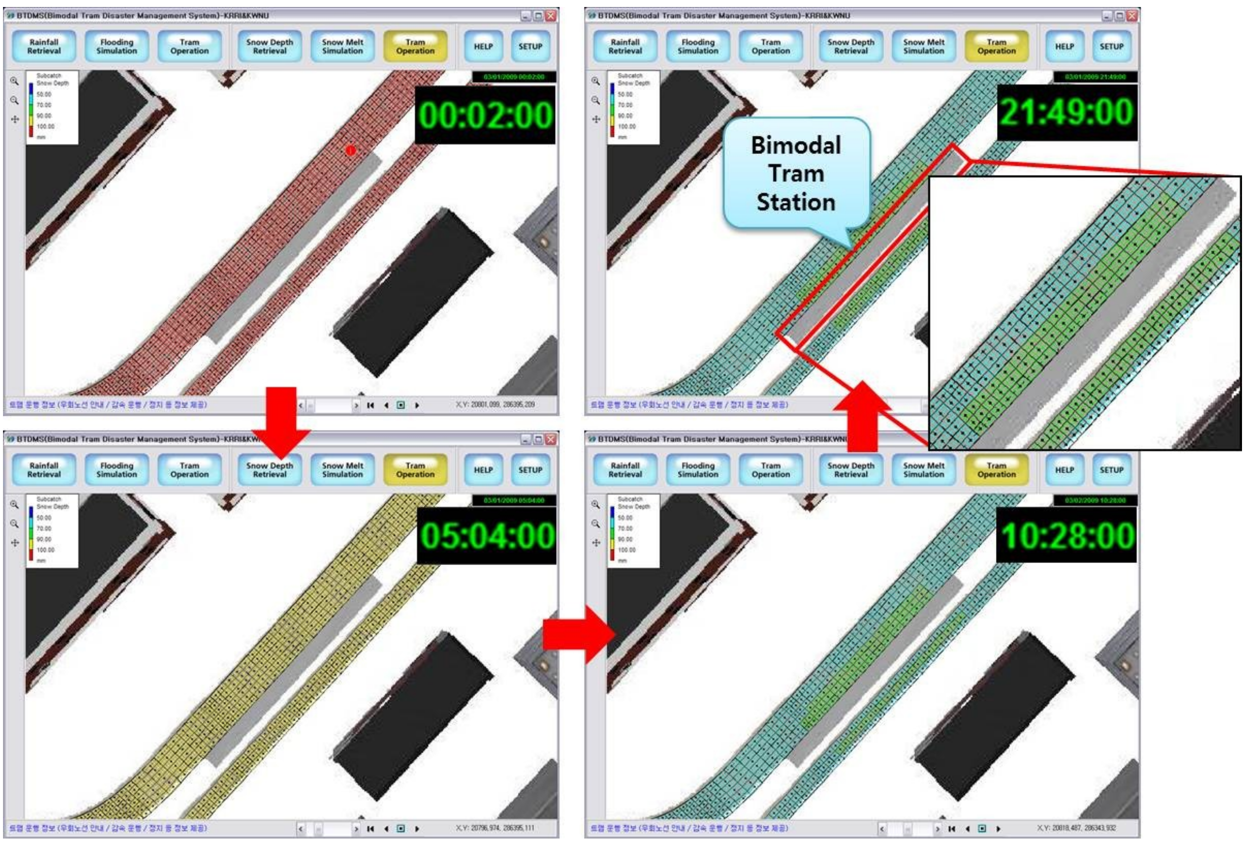

**Figure 12.** Results of flood simulation and visualization of tram ID 2.



### *4.3. Snow Melt Simulation Using BTDMS*

Snow melt was simulated in the bimodal tram railroad in the study area with BTDMS. A snow depth of 100 mm was initially assumed, and snow melt simulation was conducted after considering temperature changes for sunny and shady locations along the tramway. Also, changes in sunny and shady locations with time were included. The simulation showed that as time passed, snow melt was generated steadily in the area not shaded by the bimodal tram station. On the other hand, in areas subject to shading by the tram station, snow melt was different according to sunrise and sunset as well as the bimodal tram station blocking the sunlight. As shown in Figure 13, there were different change patterns in the snow melting process. Until 10:28, snow melting progressed steadily, but there was no more progress after 10:28. This result illustrates how the limitations of SWMM were removed so that the BTDMS could simulate snow melt efficiently and practically by considering sunrise and sunset as well as time variations in sunny and shady locations.

**Figure 13.** Results of snow melt simulation.




## 5. Conclusions

To sum up, a Web GIS-based bimodal trams disaster management system (BTDMS) has three uses. In advance, the PMF can be used to simulate behavior of the system for extreme events, and this could help in design modifications. Then, when the tram is running and a user has a weather forecast, the user can simulate where flooding might occur, so that drivers and system managers have a flood potential forecast. Then, in real time when a user has precipitation data coming in, current conditions can be simulated and real time warnings can be provided.

In this study, BTDMS was developed with newly created modules to simulate urban flash flooding and snow melt using SWMM as a core engine. For accurately simulating urban flash flooding, a design storm module, overland flow module, visualization module, and snow melt module were developed with modifications in the SWMM engine and SWMM interface. With the nation-wide design storm module using the KMA and Huff module as well as the snow melt module, the Web-based BTDMS can be applied to any location in Korea. Because of limitations in the current SWMM in simulating overland flow and snow melt, an overland flow module and snow melt module were developed for simulating overland flow from upper subcatchments to multiple downward subcatchments and for modeling both sunny spots and shade when snow melt simulation was conducted. Although these flow allocation data need to be prepared based on the flow paths and topography of the study area, these provide flexibility in simulating overland flow due to buildings and other structures in the study area affecting overland flow. The flash flooding visualization module was developed for safe operation of the bimodal tram. With this visual interface, bimodal tram operation can be rescheduled or re-directed to other safe routes in real-time. The BTDMS surface flow path module was developed for practical simulation of urban flash flooding. The Web GIS-based BTDMS will soon be applied to a test-bed route to validate its performance.

Through Web GIS-based BTDMS, it will be possible to conduct temporal and spatial analysis of flash flooding by heavy rainfall due to climate change. This system is not based on a desktop computer but is a Web GIS-based system design developed in this study, and it means that BTDMS is a Web GIS-based disaster management decision support system in the true meaning of the word. From a technology point of view, many models for modeling urban flash flooding have been developed. However, with the open engine of this system, urban flash flooding will be estimated and also optimal parameters of flooding by rainfall and snowfall can be applied to the BTDMS. From a socio-economic point of view, the GIS-based interface in the BTDMS system can be easily applied to other bimodal tram routes and utilized for other transport facilities using GIS data such as topography and sewer system data of target areas. Thus, it has benefits that additional costs other than costs to assemble new data will not be needed when BTDMS is applied to other areas. In addition to its flexible applicability, it can be a useful disaster management system for reducing the risk of damages by heavy rainfall or extreme snowfall. Thus, Web GIS-based BTDMS has the potential to reduce economic losses and reduce industrial risks and will help in efforts to achieve sustainable urban development.

Moreover, decision support systems such as BTDMS can also be used to assess and predict weather impacts on roadway conditions and operations. The methodology presented in this paper makes it possible to minimize the impact of flooding and snowfall on urban transportation and operate the bimodal tram system effectively. Such methodology based on modeling will also be available for most metropolitan areas in Korea and in many other countries. Thus, our proposed approach may provide the sustainability in the context of the transportation security and convenience to the public by being prepared and adapted against natural disasters.

Limitations of this study include that BTDMS calibration and validation with experimental data were not conducted in the study area (test bed). Monitoring systems for rainfall or snowfall were not sufficient in the current pilot bimodal tram railroad in Miryang, and experimental data were not able to be collected. Through the results of this study, however, the possibility of application of BTDMS in modeling urban flooding and in efficiently delivering warning of urban flooding in a decision support system was examined. In the near future, BTDMS will be applied with the collection of monitoring data to allow for calibration and verification in a real urban area. Based on these findings, our approach will contribute to sustainability in providing a secure and convenient transportation system that is prepared for natural disasters due to climate changes events. Moreover, because it would be useful to examine consequences of future climate change, BTDMS will be utilized to simulate the impact of the future climate change on urban transportation using downscaled Global Climate Model data.

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## Author Contributions

This research presented here was carried out in collaboration between all authors. Heetaek Yoon, Youngkon Park, and Sung Won Kang suggested/designed the research theme. Bernard A. Engel, and Younghun Jung designed the research methods and experiments. Yongchul Shin, Kyoung Jae Lim, Won Seok Jang, and Jonggun Kim conducted the laboratory experiments and the data analysis/interpretation and wrote the paper.

## Conflicts of Interest

The authors declare no conflict of interest.

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