Inundation of roads by heavy rainfall has attracted more attention than traffic accidents, traffic congestion, and construction because it simultaneously causes travel delays and threatens driver safety. For these reasons, in this paper, we propose an inundation hazard index (IHI) of road links, which shows the possibility of inundation of road links caused by rainfall. To generate the index, we have used two key data sources, namely the digital elevation model (DEM) and past rainfall records of when inundation has occurred. IHI is derived by statistically analyzing the relationships between the normalized relative height of the road links calculated from DEM within the watershed and past rainfall records. After analyzing the practical applicability of the proposed index with a commercial car navigation system through a set of tests, we confirmed that the proposed IHI could be implemented to choose safer routes, with reduced chances of encountering roads having inundation risks.

Keywords: Car navigation system, heavy rainfall, inundation hazard index, safer routing service.

I. Introduction

With the recent developments in wireless communications, microelectronics, sensors, and information technology, it is possible to provide a large amount of traffic-related information to drivers via a car navigation system (CNS). In such an environment, intelligent transportation systems (ITS) are being operated in many countries to provide traffic-related information for CNS; namely, congestion, regulation, reliable real-time travel, and hazards [1]-[3].

Among this information, weather-related information in CNS has recently attracted more attention because adverse weather conditions may not only cause traffic delays but also sometimes threaten driver safety to a significant level [4]. Finland has operated a weather-related traffic management system since November 1994. In addition to the traditional network information, it collects and provides weather-related information including wind speed and direction, air temperature, the quality of road surfaces and structure, humidity, intensity and state of precipitation, and visibility [5]. TomTom, a global company for satellite navigation, provides a weather service in its CNS products. It provides users with local daily and five-day forecasts, helping drivers make dynamic routing plans based on the weather. Drivers can also find out road conditions to ensure safe navigation [6]. Garmin International, a unit of Garmin Ltd., a global company in satellite navigation, provides Garmin XM NavTraffic. It notifies drivers of accidents, road construction, and weather-related traffic delays before they are encountered, and then offers an alternate route. It brings real-time, animated weather data directly to driver units, enabling drivers to avoid bad driving conditions caused by the weather [7]. In addition, Dash Express, known for its two-way internet-connected satellite...
navigation system, offers real-time weather information to CNS via wireless internet connection [8].

Among this additional information, the item that has practical significance for weather-related information is that concerning inundation of road links caused by heavy rainfall. This inundation by heavy rainfall causes traffic jams, restrictions to road use, and, in many cases, problematizes safe driving. So, there has been some research done to calculate travel time in rainy conditions and considering visibility and pavement friction [9]-[11]. However, inundation of road links has neither been fully studied nor utilized in any commercial CNS. Current systems only offer weather-related information that includes rainfall forecasts in the form of very simple text reports or animation [12]. If drivers receive only a weather report, it is impossible to decide whether driving conditions are hazardous or not. Therefore, there has been an increased need to offer more elaborate inundation information about road links to drivers. Based on this need, we have tried to develop a method that offers information about inundation of road links to drivers for safer routing services in CNS.

Before providing information about inundation of road links, it is necessary to predict the inundation of roads. Related research has been performed using geographic information systems (GIS) and hydrodynamic modeling. In [13], a digital elevation model (DEM) and remotely sensed images were used to model the potential for flood inundation. Using both raster and vector analyses, several models representing potential flood inundation were generated. The potential inundation surfaces were derived from regression models that related known flood elevations to river position and floodplain location. In [14], an integrated methodology for the prediction of flooded areas was developed. In the process, MIKE 21, a hydraulic numerical modeling tool, and GIS analyses are used to generate input data for the model, such as hydrologically corrected DEM, real estate, buildings, and river channels [15]. By integrating GIS techniques and hydrodynamic modeling, an efficient method is achieved for predicting flooded areas and obtaining information to manage flood events.

A model for water and energy transfer between soil, plants, and atmosphere (WetSpa), which operated on an hourly time scale was proposed in [16]. By using GIS techniques, topologies are extracted from the DEM, and soil types and land use information are obtained from remotely sensed images. They are then utilized to predict inundation areas in a watershed. Through research, it was shown that the proposed model is suitable for predicting inundation areas over complex terrain. In [17], a floodplain inundation model was also developed using GIS analyses, remote sensing techniques, and a hydrological model. Remote sensors monitored flood inundation extents for a range of flows, with monitored flood events being interpolated to create a model of flood growth. This flood growth was linked to a hydrological model of the river, making predictions of the extent of flood inundation from minimum-flow information. The GIS framework could be utilized to determine flow patterns and losses of assets across the floodplain.

In these studies, the approaches mainly focus on predicting inundated areas near watercourses or river basins. However, road networks are generally distributed across entire urban and suburban areas, not just within areas near watercourses or river basins. This makes it difficult to apply previously developed methods directly to estimating the possibility of inundation of road links in the entire region. Furthermore, there has been no research on methods for indicating the possibility of inundation of road links and how to utilize such methods in route calculations in CNS environments.

To resolve these problems, we propose a method that predicts the possibilities of inundation of road links and represents them in the form of a quantitative index called the inundation hazard index (IHI). By using the index, we can provide safety warnings to drivers or use it as a cost factor in calculating safer routes in CNS.

To achieve an accurate IHI, we first analyzed the relationship between the normalized relative height (NRH) of the road links within the watershed derived from the DEM and the amount of rainfall via statistical methods. Next, to evaluate the practical applicability of the proposed IHI, we calculated the IHI class value for every road link for a commercial CNS map currently used in the Korea market. Then, a set of tests was carried out to examine the practical applicability of the proposed IHI and the results were analyzed. Figure 1 shows the conceptual
framework of the research.

II. Proposal for the Inundation Hazard Index

The research literature shows that many variables can be considered when modeling inundated areas. In this paper, we have used two key data sources to generate the IHI of road links; namely, the NRH of road links derived from the DEM and past rainfall records that related to the inundation history of the road links. We decided on this strategy mainly because the road network covers a vast area, and it is not feasible to acquire data about drainage or soil conditions other than these two data sources. For this reason, the proposed method has some limitations. However, it also means that the proposed method can be applied easily to other areas where these two data sources are available for use. In the following subsections, detailed descriptions of the IHI derivation using these datasets and the reasons for them are provided.

1. NRH of Road Links

When it is raining, rainwater usually flows into a flat area, called a depression, which represents a real topographic spot such as the bottom of a basin, a valley, or a natural pothole, where it is impounded. In this research, we assume that a depression is the lowest area surrounded by areas of higher elevation. That is, it is the lowest area of a watershed. A watershed can be defined as a drainage basin, which is an extent of land where water from rain drains downhill into a depression or a body of water. It is separated from its adjacent watersheds. As such, we can imagine that when it is raining, rainwater falls into a depression surrounded by the separate watershed and is impounded there. From this fact, we can infer that inundation of a road link caused by rainfall occurs independently within each watershed where the link is included. Therefore, the relative height of a road link in the watershed is a crucial factor in determining inundation. Based on this scheme, we consider the NRH as one of the key factors in deriving the IHI for road links.

The process of calculating the NRH comprises three consecutive steps: delineating watersheds, assigning elevation values to road links, and calculating the NRH for road links.

A. Delineating Watersheds

To delineate watersheds, we use the elegant and efficient method using a DEM proposed in [17]. The algorithm comprises three main steps; namely, filling depressions in a DEM, computing flow directions for a DEM, and delineating watersheds for depressions.

The purpose of filling depressions in a DEM is to create an adjusted “depressionless” DEM. The original DEM always contains depressions, which hinder flow routing. By this procedure, we can generate an adjusted DEM in which the elevation values of cells contained in depressions are raised to the lowest elevation value.

By using the adjusted DEM, we can calculate flow directions over the target area (Fig. 2). The flow direction for any cell is the direction that water flows out of the cell. This flow direction is encoded to correspond to one of the eight directions that surround the center cell. There are four cases which determine flow directions.

Case 1. If the elevation of the center cell is lower than that of its eight neighboring cells, then it is a depression. It should not be present after a previous depression filling process, but it is included in the process for completeness.

Case 2. If there is only one cell among the eight neighboring cells with an elevation lower than that of the center cell, then the flow direction of the center cell is assigned as forward into this cell.

Case 3. If there are more than two cells among the eight neighboring cells with elevations lower than that of the center cell, then we use the “distance-weighted drop,” which is calculated by subtracting the elevation of the neighbor from the elevation of the center cell and dividing by the distance between them. The flow direction of the center cell is assigned forward into the cell with the smallest distance-weighted drop. If two cells on opposite sites have an equal distance-weighted drop value, then the flow direction is chosen arbitrarily.

Case 4. If the elevation of the center cell is higher than those of all neighboring cells, or is equal to those of all neighboring
cells, then we can consider that the center cell is included in a flat area for which the direction of the outflow point is not known. In this case, the flow direction is determined by an iterative process.

In the previous step, we delineated watersheds with flow directions and depressions obtained from a DEM. In this research, we assumed that watersheds are determined from those depressions and that an inundation would occur separately in each watershed. Therefore, we use depressions as starting points to delineate watersheds. Next, the extracted depressions are used as input, as rasterized cells, and the watershed for each depression is determined as the upslope area contributing flow to the given depression by analyzing the precomputed flow directions of DEM cells. Figure 3 shows the delineation of watersheds for depressions using a DEM.

B. Assigning the Elevation Value to Each Road Link

Road networks used in a general CNS have no elevation information for road links. To assign an elevation value to a road link, we converted the vector road network data to a raster image. This is a binary image for which a pixel value of one is assigned to road pixels, and zero otherwise. Then, elevation values are assigned to road pixels by overlaying a DEM. In this process, the spatial resolution of the image is the same as that of the DEM. Finally, we convert the elevation values assigned to the road network image as an attribute of the vector network data. During the process, a road link may have more than one elevation value if the length of a road link is longer than the spatial resolution of the DEM. In this case, we choose the minimum value as a representative elevation value for the link because inundation is mainly determined by the lowest part of the link.

C. Calculating the NRH

Finally, we can calculate the NRH of the road link in a watershed where it is included by using the preprocessed dataset. The NRH of each road link can be described by

$$NRH = \frac{H_L - H_{min}}{H_{max} - H_{min}}, \quad (1)$$

where $H_L$ is the elevation of a road link, and $H_{max}$ and $H_{min}$ are the maximum and minimum elevations of the watershed where the link is included.

D. Calculating the NRH for Road Links in Commercial Network Data

The process of assigning the elevation value was applied to road links in commercial CNS network data, namely, the Rousen CNS map. The road networks in this map cover the whole of Seoul, Korea, for which the area is almost 600 km² and contains 92,056 links. It has a map scale of approximately 1:1,000 and includes detailed branch lines across the whole target area. For elevation modeling of the target area, a DEM with a 10 m spatial resolution was used. The DEM has elevations from 3 m to 724 m and the average is 34.76 m. In addition, approximately 70% of pixels have values within the range 10 m to 35 m. This means that the target area has the typical geographic characteristic of an urban area: it is flat and with a terrain of relatively low elevation. Using these datasets, we calculated the NRH by applying the proposed method. As a result, the average value of the NRH was 0.284 with a standard deviation of 0.214. From this fact, we can infer that the road link is generally located in a low region of the watershed. Figure 4 shows the distribution of the calculated NRH.

2. Inundation History and Rainfall Records

We tried to access inundation histories and rainfall records. However, no current organization or database stores or manages the inundation history of roads. Therefore, to create an inundation history, we collected historical road restriction records caused by the inundation of road links. After a road is inundated, road traffic is restricted and the related historical restriction records are reported. Based on this fact, we collected...
historical restriction records from the nationwide disaster management information system of the Korean National Emergency Management Agency and news articles related to road restrictions caused by inundation of roads from July 15, 2004 to July 24, 2008. Then, we added the restriction information to each link of the road network by using the name of the road as matching information. In the process, we tried to exclude cases of restrictions from causes other than heavy rainfall, such as poor drainage of roads and car accidents. As a result, we collected historical inundation data for 1,151 road links.

To collect rainfall records corresponding to the inundation history of roads, we used the observed rainfall data from automatic weather systems (AWS), which are installed in all districts in the target area, Seoul, and are operated by the Korea Meteorological Administration (KMA). When it is raining, precipitation is measured automatically at one-minute intervals by AWS, and the records are sent to KMA via a wireless communication system. By using AWS, we could collect rainfall records for the 12 h of the day when an inundation occurred. Though it is a very accurate and convenient system, data can be missed sometimes during the measurement period through mechanical failures or transmission errors. In these cases, we regarded the data as outliers and excluded them from the final dataset. This overall process enabled us to finally construct a database for 226 road links with rainfall records for the times they were inundated.

3. Proposal for the IHI

The IHI is an index indicating the possibility of inundation of a road link according to the NRH of the road link and the amount of a rainfall in a 12-h period. In this subsection, we generate the IHI by using the reference database for 226 road links constructed via the description in II.2. In general, there is a higher chance of a road link being inundated when its NRH is relatively low. We find that the frequency of inundation is high when the NRH is in the range 0.06 to 0.20. We also find that the minimum quantity of rainfall for inundation is 60 mm, and the frequency is high when it is above 160 mm in 12 h.

To derive the IHI, we conducted a clustering analysis using the well-known $k$-means algorithm [18]. This is a method of clustering analysis that aims to partition $n$ observations into $k$ clusters, for which each observation belongs to the cluster with the nearest mean. For a given set of observations $(x_1, x_2, \ldots, x_n)$, where each observation is a $d$-dimensional real vector, $k$-means clustering aims to partition the $n$ observations into $k$ sets, $S = \{S_1, S_2, \ldots, S_k\}$, seeking to minimize the within-cluster sum of squares. This can be described as

$$V = \sum_{j=1}^{k} \sum_{i \in S_j} (x_j - \mu_j)^2,$$

where $V$ is the sum of residuals and $\mu$ is the mean of $S_j$.

When applying the $k$-means algorithm, the value for $k$ is specified either randomly or by some heuristic algorithm. In this paper, it is determined empirically. By applying the $k$-means algorithm for various values of $k$, we concluded that the reference dataset is well clustered and reflects the characteristics of its distribution when $k$ is three. Figure 5 shows the clustered dataset in which the scatter plot shows the NRH and 12-h rainfall for the reference database and the 3D bar graph shows the count.

Based on the clustering results, we propose an IHI with four different class levels according to the possibility of inundation; namely, bare (level 1), low (level 2), high (level 3), and strong (level 4). From Fig. 5, we identify that inundation of a road may occur if the NRH is less than 0.3. Equally, we can infer that the possibility of inundation is very rare if the NRH is higher than 0.3. In addition, we can infer that the possibility is...
very rare if the 12-h rainfall is less than 60 mm because there are no inundation records in the reference data. Therefore, for those situations, the IHI is assigned a level of 1, meaning a bare possibility. Conversely, if the 12-h rainfall is above 60 mm and the NRH of a road is greater than 0.3, then there is a chance for the road to be inundated. Moreover, there is a greater chance for a road to be inundated as the 12-h rainfall measurement increases. Therefore, by considering the clustering result, we propose a further three levels of IHI according to the 12-h rainfall. Although the frequency is relatively low, there is a possibility for a road to be inundated if the 12-h rainfall is in the range 60 mm to 160 mm, and the IHI is assigned a level of 2, or low possibility. If the 12-h rainfall is in the range 160 mm to 180 mm, we consider the possibility of inundation to be higher than in the previous case. We can identify this fact from Fig. 5, in which the frequency of inundation is very high in this range. Therefore, the IHI is assigned a level of 3, or high possibility. In particular, if the rainfall is above 180 mm, the IHI is assigned a level of 4, or strong possibility. We see that a road is inundated if the rainfall is 200 mm even though its NRH is almost 0.3.

Table 1 summarizes the proposed IHI.

<table>
<thead>
<tr>
<th>IHI</th>
<th>Meaning</th>
<th>NRH</th>
<th>12-h rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Bare possibility</td>
<td>NRH &lt; 0.3</td>
<td>0 mm ≤ rainfall &lt; 60 mm</td>
</tr>
<tr>
<td>Level 2</td>
<td>Low possibility</td>
<td>NRH &lt; 0.3</td>
<td>60 mm ≤ rainfall &lt; 160 mm</td>
</tr>
<tr>
<td>Level 3</td>
<td>High possibility</td>
<td>NRH &lt; 0.3</td>
<td>160 mm ≤ rainfall &lt; 180 mm</td>
</tr>
<tr>
<td>Level 4</td>
<td>Strong possibility</td>
<td>NRH &lt; 0.3</td>
<td>180 mm ≤ rainfall</td>
</tr>
</tbody>
</table>

III. Experiments

1. Finding Safer Routes Using the IHI of Road Links

In order to evaluate the practical applicability of the proposed IHI, we designed several tests in which the safer route was to be calculated when the IHI of road links was already incorporated. The tests were conducted in the Rousen CNS, which is a car navigation product currently used in the Korean market. The road map in the Rousen CNS map is constructed from the NAVTEQ Map for South Korea. It is produced in Geographic Data File (GDF) format [19], an international standard used to model, describe, and communicate road networks and road-related data. The road networks in the map cover the whole of Seoul, Korea. The attribute information includes road characteristics, such as speed limits, link lengths, road classes, number of lanes, travel directions, and the existence of signals. The IHI of the road link is added as another field of attribute information (see section II.1).

In the Rousen CNS, an optimal route, which is a route with minimum cost, is calculated via the bidirectional A* algorithm [20], [21]. The program runs two simultaneous A* algorithms for accelerated search: one forward from the initial point and one backward from the goal, stopping when the two searches meet in the middle. The A* algorithm is a best-first graph search algorithm that finds the least costly path from a given initial point to one goal point. To find the optimal route, it uses a distance-plus-cost heuristic function, which is defined as the sum of two functions: the path-cost function \( g(x) \) and an admissible “heuristic estimate” cost function to the goal \( h(x) \). In other words, \( g(x) \) means the shortest distance traveled from the initial point to the current point, with \( h(x) \) being the estimated remaining distance from the current node to the goal. The optimal path will then be determined by minimizing \( f(x) \), where

\[
f(x) = g(x) + h(x).
\]

When using the A* algorithm, the cost function can be calculated and estimated using various factors, such as the sum of distances or the “necessary time.” In this paper, we use the necessary time to travel from an initial point to the goal point to estimate the cost function. Therefore, related attributes of road links used in calculating cost function are converted into the necessary time to pass the specific road link. They are, for example, the average velocity of a link, the length of a link, and a signal waiting time. In the same way, the IHI class value also has to be converted into a necessary time cost to pass the specific link. Therefore, when a road link has an IHI at level 4 (strong possibility), the necessary time is assigned a value of 120 min, and when a road link has an IHI at level 3 (high possibility), the necessary time is assigned a value of 60 min. Because there has been no previous research done to show the necessary time cost for IHI at level 3 or level 4 inundation cases, these time costs were determined by interviewing experts in five police stations. Their statements implied that the assigned time duration is generally the time required to escape from the road link when it is inundated.

To calculate the optimal route when considering the IHI of road links, we designed four different options. The user selects one, and then the optimal route is calculated according to that option. The options are as follows.

Option 1. Current routing: Calculate the optimal route without considering the IHI of road links, that is, the optimal route provided in commercial CNS.

Option 2. Avoid roads with an IHI at level 4: Calculate the optimal route, considering the IHI of road links at level 4. Here, the optimal route will usually avoid road links with a strong
inundation possibility.

**Option 3.** Avoid roads with an IHI at levels 3 or 4: Calculate the optimal route, considering the IHI of road links at level 3 or level 4. Here, the optimal route will usually avoid road links with a strong or high inundation possibility.

**Option 4.** Seek roads with an IHI at levels 3 or 4: Calculate the optimal route, considering the IHI of road links at level 3 or level 4. Here, the optimal route will be guided towards road links with a strong or high inundation possibility.

If the user chooses option 1, the optimal route will be calculated in the current method without considering the IHI of road links. Otherwise, if the user chooses option 2 or option 3, the IHI of each link is considered as a cost factor in the bidirectional A* algorithm. In option 2, the IHI of the link is only considered when its level is 4, which means that the possibility of inundation is strong. In option 3, similarly, the IHI of the link is considered when its level is either 3 or 4, which means that the possibility of inundation is high or strong. In option 4, which is designed for special purposes such as rescuing people or vehicles on inundated roads, the optimal route will be calculated to guide the user towards roads with a high or strong possibility of inundation. In this process, the necessary time cost assigned to a road link with an IHI at level 1 or 2 is 120 min or 60 min, respectively, in contrast to the option 2 or option 3 cases.

2. Tests and Results Analysis

The tests were conducted using sample datasets selected from the Rousen CNS map and past rainfall data. The rainfall datasets were collected on July 15, 2001 and July 16, 2006 from 25 AWS, which were well distributed over the whole Seoul area. Following the proposed method, we calculated the IHI values and then stored them as an additional attribute of road links in the map database.

Figure 6(a) shows the calculated IHI of the dataset collected on July 15, 2001. At that time, there was heavy rainfall of over 200 mm. Therefore, many road links had an IHI at level 4 and some of them had an IHI at level 3. Though there was heavy rain, the road links with large NRH had an IHI at level 1.

The second dataset was collected on July 16, 2006. At that time, there was an average 169 mm of rainfall. From Fig. 6(b), we see that many road links had an IHI at level 1 or level 3 and some of them had an IHI at level 2 or level 4. Next, we arbitrarily selected 10 origin-destination pairs for each date and calculated the optimal routes, meaning that 20 cases were prepared for the tests. For each case, an optimal route was calculated for all four of the options described above. Figures 7 and 8 show the resulting percentage of road links with a specific IHI included in the calculated optimal route in each option, for July 15, 2001 and July 16, 2006, respectively. At Fig. 7, we need not describe IHI at level 2. Because there are no road links of IHI at level 2 on July 15, 2001 so that the road links with IHI at level 2 on this day are not included.

From Fig. 7, it is found that the road links with an IHI at level 4 are generally included less frequently in the routes for option 2 than for option 1. For option 3, the road links with an IHI at level 3 or level 4 are also included less frequently in the routes than for option 1. For option 4, intended for special purposes, more routes are found that guide towards road links with an IHI at level 3 or level 4, when compared to the results for other options. Figure 8 contains similar results to those in Fig. 7. Generally, the road links with an IHI at level 3 or level 4 are included less frequently in the routes for options 2 and 3 than for option 1, while they are included more frequently in the routes for option 4.

In Fig. 7, the results for option 2 are similar to the results for option 3 (see routes 4, 5, 6, 8, 9, and 10). This follows from the fact that road links were mainly classified with an IHI at level 4 rather than level 3 on July 15, 2001 because there was a heavy rainfall of over 200 mm. Figure 9(a), for example, shows route 4 from Fig. 7. In Fig. 9(a), road links with an IHI at level 4 or level 1 are mainly distributed in the area near the route. In Fig. 8, the results in option 2 are similar to the results in option 3 because of the low IHI of 3 near the origin or destination (see routes 6 and 9). Figure 9(b) shows route 9 from Fig. 8. In Fig. 9(b), road links with an IHI at levels 1, 2, 3, or 4 are distributed evenly in the area near the route, but there are only road links with an IHI at level 4 near the destination. The results for options 2 and 3 are similar.

Figure 8 clearly shows that road links with an IHI at level 3 or level 4 are included less frequently in the routes for option 3 than for option 1. Furthermore, in routes 4, 5, 8, and 10, the same routing results are returned for options 1 and 2. This is because there are no road links with an IHI at level 4 in the area near the routes. Although there are no differences between options 1 and 2, we see that road links with an IHI at level 3 appear less frequently for option 3 than for option 1.
Fig. 7. Percentage of road links with a specific IHI included in the optimal route (July 15, 2001).

Fig. 8. Percentage of road links with a specific IHI included in the optimal route (July 16, 2006).

Fig. 9. Examples of optimal routes: lanes outlined with dashed lines are the calculated optimal routes.

Fig. 10. Examples of optimal routes: lanes outlined with dashed lines are the calculated optimal routes.
In certain cases, we get the same results for options 1 and 2 even though road links with an IHI at level 4 are included in the route. This occurs for route 10 in Fig. 7 and routes 7 and 9 in Fig. 8, just like in Fig. 10. For route 10 in Fig. 7 and route 9 in Fig. 8, most of road links in the areas near the origin and destination have an IHI at level 4, preventing road links at other IHI levels from being detected. For route 7 in Fig. 8, the road links on the highway are mainly selected for the optimal route. In this case, the alternatives are not detected until the highway ends, giving the same results for options 1 and 2.

Figure 11 shows the calculated routes according to the four different options for route 1 in Fig. 7. Lanes outlined with dashed lines are the calculated optimal routes in each option.

Based on the test results shown in Fig. 11, we can confirm that the proposed IHI applies in practice to the calculation of safer routes. As the resulting routes showed, drivers can minimize their chances of encountering road links with a strong or high possibility of inundation during navigation.

IV. Conclusion

In this paper, we have proposed an IHI to provide safer routing services to drivers in CNS environments. To derive the IHI, we used two key datasets; namely, the DEM and past rainfall records related to the inundation history of road links. From the DEM, the NRH of road links in the watershed area are calculated. By statistically analyzing the NRH of road links and the corresponding inundation history from rainfall records, we can derive the IHI. Such an IHI is believed to represent the possibility of inundation of each road link at four different class levels. To examine the practical applicability of the derived IHI, we applied the IHI calculation approach to a commercial CNS map product. This enabled IHI class levels to be generated for all road links in the map. An appropriate time cost was then assigned to each IHI class level to calculate the optimal routes for four different options. Having completed a set of tests, we can confirm that a routing service that includes an IHI can be used for safer navigation. The implication is that we can avoid the number of road links that have a high possibility of inundation along the route by using the IHI. In other cases, it could be used to guide drivers to inundated roads for special purposes such as rescuing people or vehicles.

Although we derived the IHI by using the DEM and past rainfall records, there are many other factors to be considered, including river flooding, soil types, and drainage conditions. To develop a more reliable IHI, research into these factors should be undertaken. Therefore, we believe that this research is just one cornerstone in the development of a better IHI.

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Jiyoung Kim received her BS in geography, Konkuk University, Korea, in 2001. She received her MS in GIS and remote sensing from Seoul National University, Seoul, Korea, in 2009. She is now a PhD student of the Department of Civil and Environmental Engineering, Seoul National University in Korea.

Jaebin Lee received his BS in civil engineering from Yonsei University, Korea, in 2000. He received his MS and PhD in GIS and remote sensing from Seoul National University, Korea, in 2002 and 2008, respectively. He is now an assistant professor in the Department of Civil Engineering, Mokpo National University in Korea.

Won Hee Lee received his BS in civil engineering from Yonsei University, Korea, in 2000. He received his MS in GIS and remote sensing from Seoul National University, Korea in 2003. He received his PhD in geodetic science from Ohio State University, in 2008. From 2007 to 2009, he was a research scientist at Qbase, Dayton, Ohio. Since then, he has been with the Department of Civil and Environmental Engineering, Seoul National University as a BK21 contract professor.

Kiyun Yu received his BS and MS in civil engineering from Yonsei University, Korea, and his PhD in GIS from the University of Wisconsin, USA, in 1998. He was a director in the Ministry of Construction and Transportation until 2000. He is now an associate professor in the Department of Civil and Environmental Engineering, Seoul National University, Seoul, Korea.