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Original Article

Development and Utilization of a Rapid and Accurate Epidemic Investigation Support System for COVID-19

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ABSTRACT

Objectives: In this pandemic situation caused by a novel coronavirus disease in 2019 (COVID-19), an electronic support system that can rapidly and accurately perform epidemic investigations, is needed. It would systematically secure and analyze patients' data (who have been confirmed to have the infection), location information, and credit card usage.
Methods: The "Infectious Disease Prevention and Control Act" in South Korea, established a legal basis for the securement, handling procedure, and disclosure of information required for epidemic investigations. The Epidemic Investigation Support System (EISS) was developed as an application platform on the Smart City data platform.
Results: The EISS performed the function of inter-institutional communication which reduced the processing period of patients' data in comparison to other methods. This system automatically marked confirmed cases' tracking data on a map and hot-spot analysis which lead to the prediction of areas where people may be vulnerable to infection.
Conclusion: The EISS was designed and implemented for use during an epidemic investigation to prevent the spread of an infectious disease, by specifically tracking confirmed cases of infection.

Introduction

Coronavirus disease 2019 (COVID-19) has spread throughout the world, creating public health crises globally and nationally. As of April 20th, 2020, there were about 2.85 million confirmed infections globally, which has resulted in 160,000 deaths. Since January 20th, 2020, when the first confirmed case was identified at a South Korean airport during a preventive test, a further 10,661 confirmed cases have been reported within the country. Despite the rapid increase in confirmed cases mainly due to a cluster of infection in Daegu in February 2020, the average number of daily confirmed cases between April 29th and May 5th has been suppressed (n = 7.42) by following the 3T policy (test, trace, and treat) as of April 19th, 2020 [1].

The "trace" aspect of the 3Ts, corresponds to the investigation of the epidemic. It confirms the reliability of the

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data given during the interview with the infected individual by using location information, credit card usage and closed-circuit television, to identify the presence of the confirmed COVID-19 infected individual, as per the "Infectious Disease Prevention and Control Act" [2].

The daily reproduction number (Rt) of COVID-19 was reported in Wuhan, China, as a Rt of 2.35 (95% CI: 1.15-4.77) before the lockdown and 1.05 (0.41-2.39) after lockdown measures were implemented [3]. However, it has been reported that SARS-CoV-2 is infectious before the manifestation of symptoms of COVID-19 [4,5]. This understanding of the spread of disease enables rapid epidemic investigations and isolation of the infected individuals, thereby preventing transmission of COVID-19. In South Korea, those who have come into close contact with confirmed cases of COVID-19 have been isolated and tested; this followed rapid epidemic investigations without enacting a blockade policy. Since more types of information have been made available for epidemic investigation (due to changes made via the legal system), more time was needed to secure the relevant information and perform analysis (24-48 hours). To overcome time limitation of data processing, the demand to develop a system increased. As such, the Ministry of Land, Infrastructure and Transport, and the Korea Centers for Disease Control and Prevention, jointly developed the "Epidemic Investigation Support System" (EISS).

This article aims to introduce the legal and technical background of the development of the EISS, with a brief explanation about the system and its functions, and compare this application to those developed outside South Korea for the purpose of preventing the transmission of COVID-19.

Materials and Methods

1. Legal background

The "Infectious Disease Prevention and Control Act [6]," and the "Enforcement Decree of the Infectious Disease Prevention and Control Act [7,8]" (hereafter referred to as the Infectious Disease Prevention Act), have led to the enactment of the legal standards (those requests made by the Police Department, and the receipt of results) used in securing location information of infectious disease patients' data, which is normally retained by mobile network companies. Additional data which can be collected for tracking includes the details of credit card usage, transportation card usage, visits to medical institutions, entry, and departure from the country, and closed-circuit television video footage (Figure 1). In addition, the Infectious Disease Prevention Act has a provision to rapidly disclose the tracking information of infectious disease patients, depending on the outbreak situation.

The provision for the use of personal information in the Infectious Disease Prevention Act was amended, along with its disclosure of information for tracking purposes, at the time of the Middle East Respiratory Syndrome outbreak in

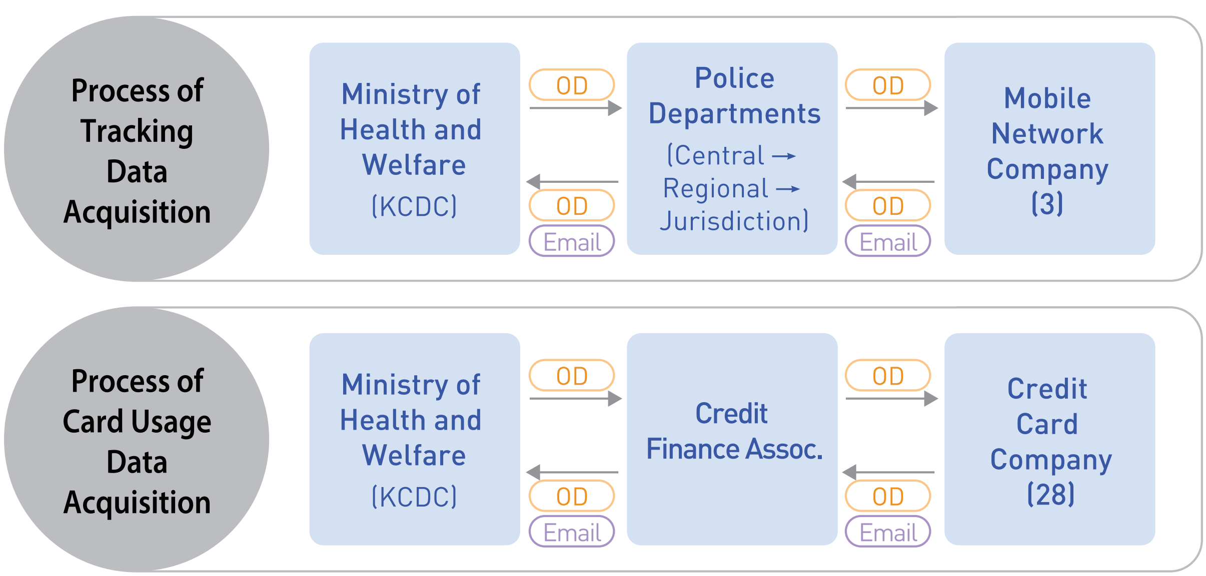

Figure 1. Data collection procedure and data flow according to the "Infectious Disease Prevention and Control Act." OD = official document.

2015 (July 6th, 2015). To prevent the introduction and spread of dangerous infectious diseases, the Act was amended to enable the use of specific measures to rapidly control infectious diseases in the early stage of inflow. The Act achieves this by endowing public officials in the field of epidemic prevention, the practical authority to enable them to take rapid and appropriate measures, and to disclose information about infectious diseases.

2. Technical background

All mobile phones have been designed to periodically communicate with nearby base stations (using a relatively strong mobile signal) when the phone is powered on, regardless of use.

As of 2019, the rate of smartphone use among Korean adults was 95%, almost reaching 100% when 2G phones were included [9]. As of February 2020, 3 major mobile network companies, (including SKT, KT, and LGU+), had an estimated 90% of the market share in South Korea, while MVNOs (Mobile Virtual Network Operator) had a market share of 11% [10]. Since the MVNOs use the networks of the 3 major companies, the location and base station access information of mobile phone users is stored on the databases of these 3 companies.

According to the spectrum map (http://www.spectrummap.kr) run by the Korea Communication Agency, the number of base stations per 1,000 people in 2019 was 29.7 (14.8 stations/km^2). As of March 2020, 4G (LTE) which is used by 55.6 million (80.7%) mobile phone subscribers in South Korea covered an estimated 2.0-2.5 km radial area from base stations located in suburban areas, and an estimated 200-300 m in urban areas according to the coverage maps of each company, where users are more concentrated. As for commercial 5G services as initiated in South Korea on December 1st, 2018, for the first time in the world, 4.9 million mobile phone subscribers (7.2%) were making use of this technology as of March 2020. These users are serviced by 109,000 base stations operating in 85 cities (with each city having a population greater than 50,000 people). 5G covered an 80-100 m radial area from base stations located in urban areas within Seoul.

3. System background

In 2016, the Korean Government selected various National Strategic Projects that would be prioritized and which would have far-reaching effects in the Science and Technology Strategy Conference. The creation of new industries and the improvement of people's quality of life were among the targets identified at the conference. Among these new industries was the Smart City Project, which is the fundamental system used by the EISS. This project led by the Korean Ministry of Land, Infrastructure and Transport and Ministry of Science and ICT since 2018 aims to collect urban data to be used in solving urban problems concerning (among others) transportation, safety, administration, environment, energy, quality of life, and welfare. Data collection is also intended to aid in the construction and operation of large-scale systems which can analyze the collected data. The project was originally planned to conduct an empirical study in Daegu between 2020-2021, which was to be followed by an initial introduction of the system. However, this was canceled due to the mass outbreak of COVID-19 in Daegu in February 2020. Subsequently, the directors of the project proposed the application of the system to be for tracking confirmed COVID-19 cases instead of conducting the empirical study, leading the Ministry of Land, Infrastructure and Transport to develop a concept system. Thereafter, the Center for Infectious Disease Control in the Korea Centers for Disease Control and Prevention, which is responsible for prevention of epidemics (including investigations of epidemics), applied it. As a result, various methods used in real epidemic investigations, along with examples, have been used to test the system for a month. During this time, the department in charge reviewed (in advance) whether replacements of existing documents, data and spreadsheets requests made by e-mail, responses to the requests made, analyses of results, and the application procedures practiced with information obtained by the system, would be appropriate in terms of security control (which was reviewed in parallel).

4. The EISS

The EISS has been developed as an application platform on the Smart City data platform. This platform centers on the Data Hub Core, acting as a means for receiving data (via Hub Connectivity to the legacy platform); a portal for semantic analysis, a visualization engine, and web service; an application programming interface for inter-server connection; a security module; a monitoring system; and a cloud management system (Figure 2).

From the viewpoint of an epidemic investigation support system, the existing system present in the local server would pose difficulties in rapidly establishing new computing resources required for the collection of tracking data and the analyses thereof when the number of confirmed cases increases rapidly. In contrast, the EISS has been constructed upon the foundation of the previous cloud-based Smart City data hub platform, which has the advantage of an easy and quick acquisition of resources for operation.

In addition, the government offices of South Korea run the intranet and internet separately to prevent security risks, such as hacking. The EISS for COVID-19 that is, a Smart City data hub platform requiring multiple externally-connected data

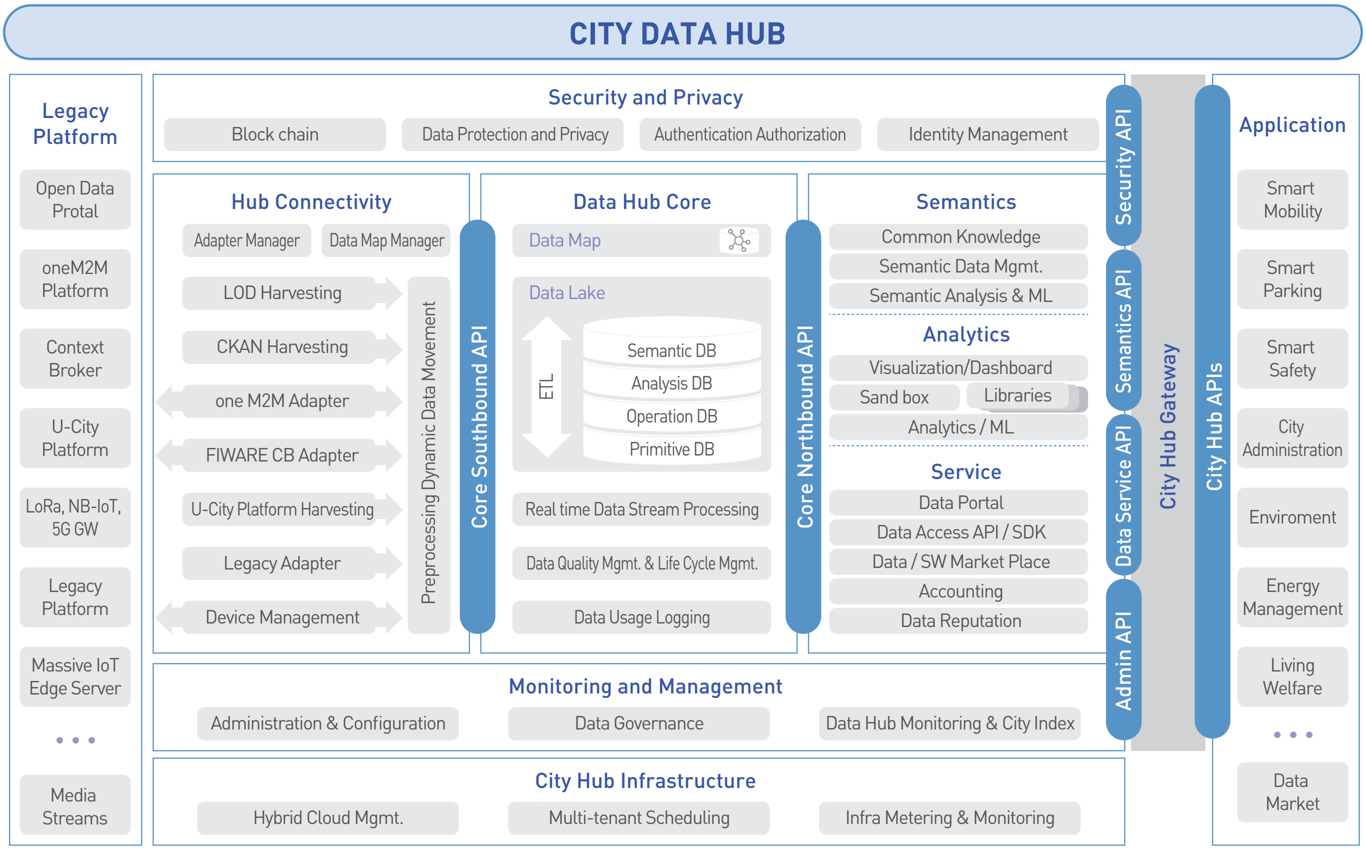

Figure 2. The structure of the "City Data Hub." The system modules of the City Data Hub, as loaded on the cloud system TOAST G, managed by the system NHN.

points (mobile network companies and credit card companies) required system efficiency, and multiple external connections. Thus, the EISS has been installed on the cloud system TOAST G, managed by a system (NHN) that has already acquired security authentication from the relevant authority.

Results

1. Procedure to use the system

First, the Korea Centers for Disease Control and Prevention enters information of confirmed COVID-19 cases. The system only provides the tracking information of confirmed cases of COVID-19 (those cases which have been given a case number by the Korea Centers for Disease Control and Prevention). This limitation allows for the system to comply with the policy restricting and managing the range of investigation within an epidemic, as stated by the law, and applies to the acquisition and utilization of tracking information that is considered as sensitive personal information.

After the entry of the confirmed COVID-19 case information, an epidemic investigator requests the case information required for tracking via the system. As for information from the mobile network companies, a corresponding request goes through the approval procedure via the Police Department. For card usage information, the Credit Finance Association identifies the cards that the confirmed case in question possesses, followed by a request to the corresponding credit card companies for information.

Once the request for information has been placed, the mobile network companies and the credit card companies conduct a search against their own databases using the name of the confirmed case, mobile phone number, and card number, and upload the data onto the EISS using a standard format. As for writing, each company either uses automation, or has allocated staff to manually search the databases, enter the data according to the required format, and upload them to the EISS.

In terms of acquiring information for tracking a mobile phone, about 2,000 cases/day are collected, based on estimations of periodic communications between the mobile phone of the confirmed case and mobile base stations. The maximum period for which a search can be conducted is restricted to the length of the disease's incubation period; this is to minimize unnecessary acquisition and exposure of personal information. During the maximum search period for cases of COVID-19 (14 days), 28,000 cases of access information (the latitude and longitude information of the base station, along with the time) have been obtained to date. In contrast, the previous manual tracking analysis method required the identification and classification of locations based on latitude and longitude, as well as visit duration by location, before marking the information on the map based on the classifications identified. Since the mobile communication network automatically accesses a base station with the strongest signal, a nearby mobile base station is sometimes connected instead of the closest base station. In the case of movement by car or high-speed train (KTX, 300 km/hour), tracking fails to be connected, and a mobile base station far from the moving path is sometimes connected instead. Using the previous manual method of tracking, the staff had to check each case to delete inaccurate information from the moving path, or correct it (Figure 3).

2. Tracking analysis on confirmed cases

The major function of the EISS is that it receives the access information for mobile base stations of mobile network companies and card usage information while tracking the confirmed COVID-19 case and automatically marking the tracking data on the map. When information is processed using the manual method, the moving time and speed are first analyzed, after which any incorrect information such as locations and time period of distant base stations identified by tracking is analyzed using AI, followed by marking the map according to the time period (Figure 4). In addition, the EISS first analyzes whether a particular spot simply happens to be on the moving path, or results from a social activity involving other contacts via the automatic analysis of visit duration, and then reports the information to an epidemic investigator. The epidemic investigator supplements any incompletely secured tracking information through an interview, based on the data presented. This allows not only for locations visited to be identified, but also the investigator to assess whether these visits resulted in a social activity through an additional interview with the confirmed case, if necessary.

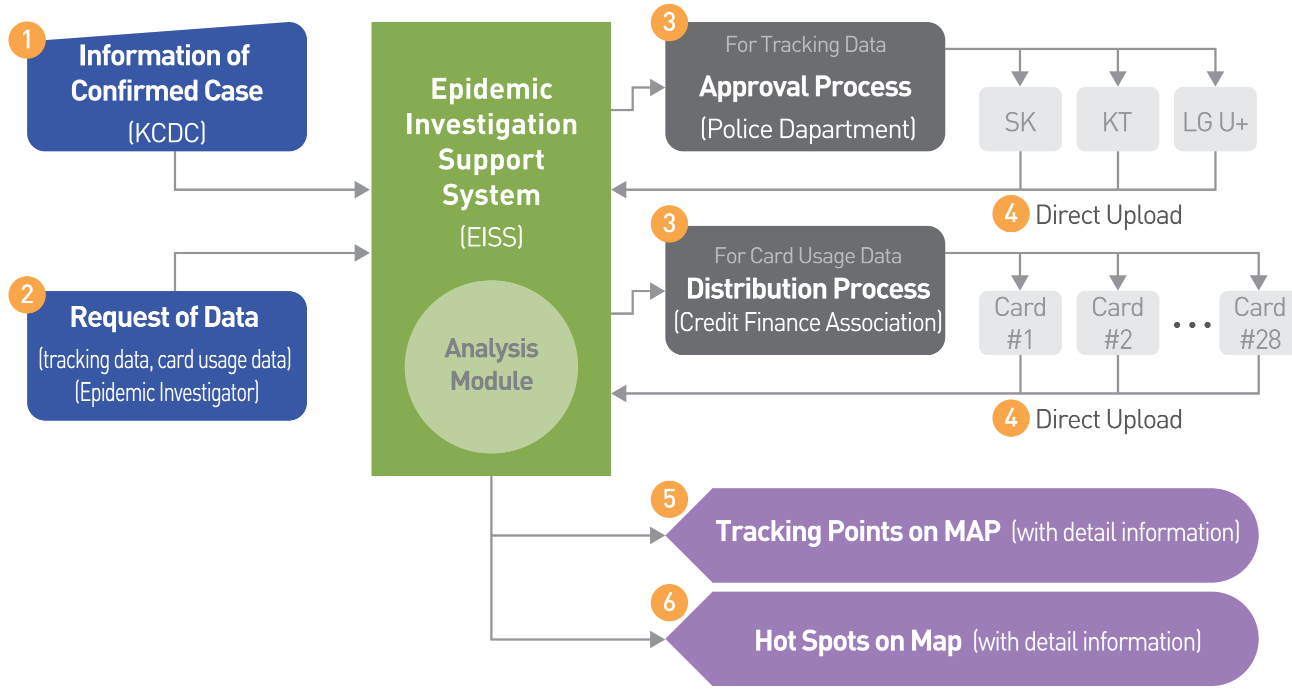

Figure 3. Data flow via the EISS. 1) Entry of information concerning confirmed COVID-19 cases; 2) Data requests made by local governments and central epidemic investigators; 3) Approval given by the Police Department, and search and distribution details provided to credit card companies by the Credit Finance Association; 4) Upload of the access information to mobile base stations (time period, as well as latitude and longitude location information) and card usage details (credit card member store information such as name, address) for requested confirmed cases; 5) Presentation of tracking information for confirmed COVID-19 cases, as analyzed via the use of uploaded data; 6) Presentation of analysis results (hot spots) concerning the tracking data for confirmed COVID-19 cases.

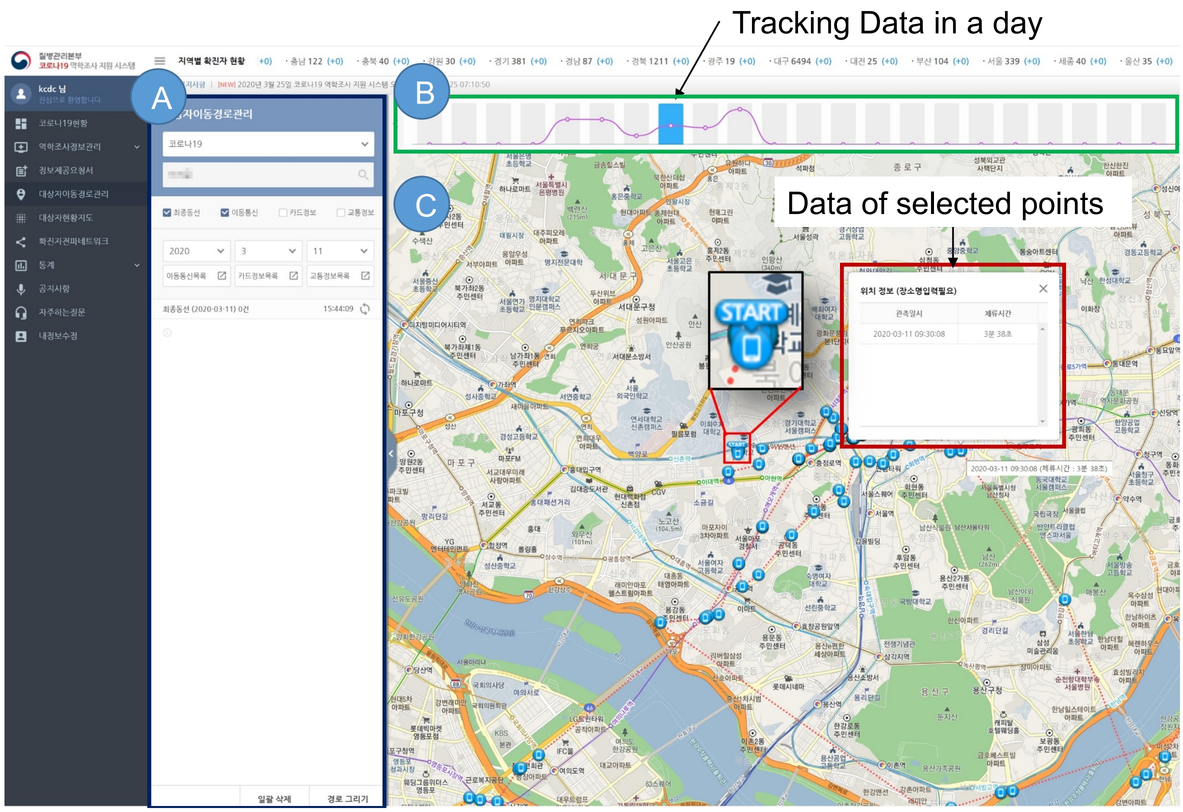

Figure 4. Presentation of tracking information in the EISS. (A) is the area where requested tracking data for confirmed COVID-19 cases can be entered. It entails functions for the editing (i.e., remove and insert) of tracking data according to an interview and finalization of the tracking data; (B) indicates the area where the tracking data of a selected confirmed COVID-19 case can be searched for according to the day. A rectangle indicates the day, while the line graph is indicative of the amount of tracking data acquired on the day in question; (C) is a map where tracking data can be shown that is based on the access information to mobile base stations. When a point is clicked, the data of the access date and visit duration at the point are displayed.
*The tracking data presented in this figure is just an example (as analyzed by using the access information on the developer's mobile phone), which is not tracking information for a confirmed COVID-19 case (tracking data for confirmed cases are only used in epidemiological investigations).

In addition, data from credit card companies can confirm data relating to specific locations (e.g. service businesses such as restaurants, cafes, and libraries), which are then included in the tracking information regarding the confirmed COVID-19 case. Information from mobile network operators and credit card companies include the time observed at the point of data capture, allowing for information to be synchronized across time via the EISS server, negating the requirement for additional time corrections.

Finally, confirmed tracking information is disclosed to the relevant local residents through the homepage of the local government, or disaster warning text message service.

3. Hot spot analysis functions

This system has constructed and managed a database of tracking analysis results of individual confirmed COVID-19 cases. Tracking data of confirmed cases can be easily overlaid spatiotemporally, which enables the prediction of the routes of infection between confirmed cases. In addition, it is possible to analyze hot spots, which leads to the prediction of areas vulnerable to infection.

Figure 5 is a presentation of numbers resulting from the automatic analysis of spatiotemporal tracking data of all confirmed COVID-19 cases. One can easily identify a place by simply clicking a corresponding number, which then presents the relevant confirmed number of COVID-19 cases relating to that location.

Since such hot-spot analysis requires tremendous computing resources, the system processes this analysis as a batch during the night. This minimizes any delay for users that may be caused by hot-spot analysis in the system.

4. Effective and safe management of data

Using the methodology that was previously used for securing

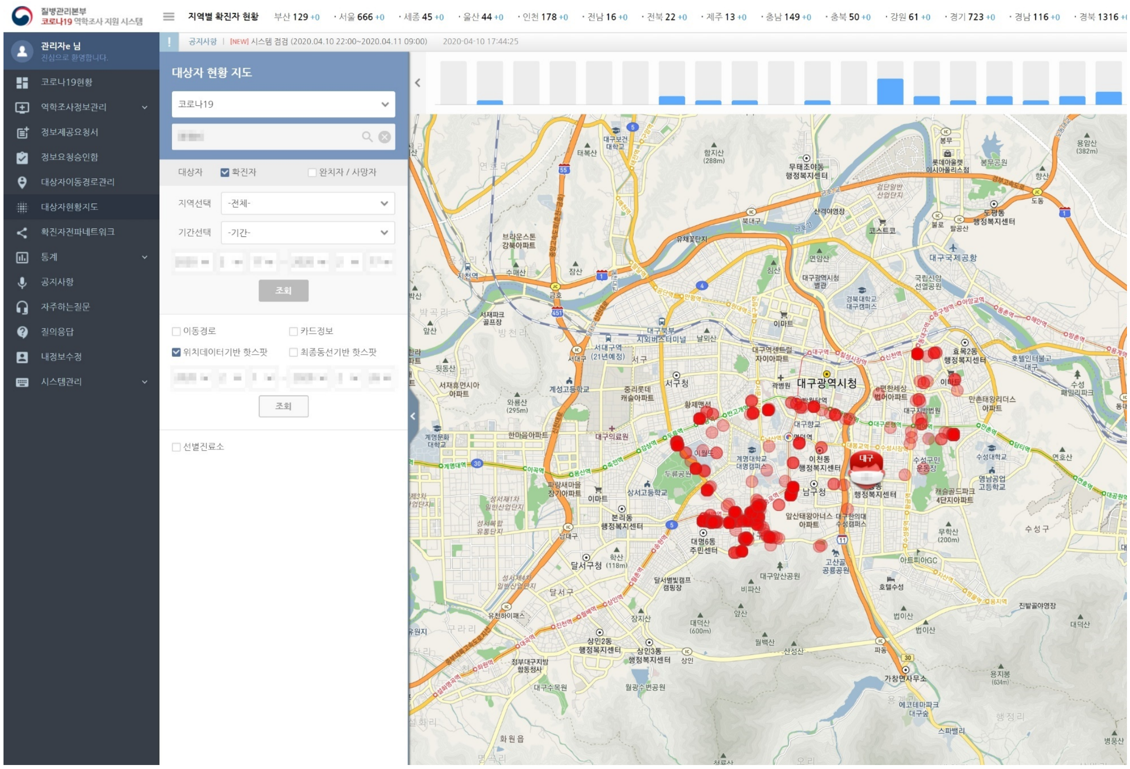

Figure 5. Hot Spots presented by the EISS. In this screen, hot spots can be identified. These hot spots as graded in levels, depending on the extent of its overlap with other confirmed cases amongst the tracking data of all confirmed cases that have been entered into to the EISS. It has become anonymized to prevent the identification of specific confirmed COVID-19 cases. The map function can be zoom in and out. It can also determines which confirmed COVID-19 cases overlapped in the tracking path when an individual point is selected (data not shown).

Table 1. A comparison of before and after the construction of the EISS system.

Division	Before	After
Tracking analysis of confirmed COVID-19 cases	Manual analysis by epidemic investigators (about 24 h)	Automatic analysis by the system (within 10 min)
Access control of personal information	Handwritten, manual, limited in control	Automatic control through digitized records
Inter-institutional work system	Individual contacts made to each institution, excessive work and delays in contacts due to handwriting and manual nature of requests	Real-time information exchanges among 28 institutions via the system

EISS = Epidemic Investigation Support System.

and analyzing data along legally regulated processes, the staff in charge of each step had to request personal information through the intranet system or via an official letter, whereas personal information obtained from each company had to be sent by email. This resulted in numerous weak points in the system's security. In addition, the staff in charge often noticed the requests or emails received during the night midweek or at the weekends, resulted in increased time spent on requesting and receiving data, to apply to the epidemic investigation. Moreover, relatively speaking, there was a greater chance of security incidents such as the leaking of personal information by staff handling the data.

The EISS performs the function of inter-institutional communication which reduces the processing period in

Figure 6. Infographic of the network spread from confirmed cases. An index COVID-19 case confirmed by the epidemic investigation. 2nd-Nth infected cases are displayed. The relationships and locations of transmission can be identified.

comparison to that of more manual methods (Table 1). Furthermore, the EISS is run on the basis of a system operation policy in order to reduce security vulnerability caused by systems that need to store a large amount of personal information. The system operation policy limits the authority to access the system to epidemic investigators who are endowed with the necessary legal authority, and have completed a double check-in (based on ID, and password via one-time passwords) when accessing the EISS on the cloud through a virtual private network. Moreover, the whole databases have been encrypted. These safeguards can effectively defend the system even when log-in details and passwords are stolen, such as by hacking. All measures in the system are automatically recorded in its log in case of any security incidents. In addition, the cloud has been protected by a firewall and an intrusion detection system that has passed the national security test on the cloud system TOAST G, managed by the system NHN. Furthermore, security testing has been successfully carried out using mock hacking tests.

5. Other functions

A feature of the EISS is an infographic presentation of the infection routes as identified by epidemic investigation of confirmed cases. The infographic presentation concerning the routes of infection (such as who infected who, and where) has enabled the rapid identification of various situations more easily (Figure 6).

In addition, the EISS provides information concerning major hot spots of infection as identified by the hot-spot analysis, which presents evidence to estimate risks associated with specific locations.

Discussion

The EISS has been designed and is in use as a system for epidemic investigations, and the prevention of the spread of infectious diseases, particularly through the capacity to track confirmed cases of infection. It is not a surveillance system targeting numerous unspecified people. In South Korea, people have agreed that infectious disease information should be disclosed transparently and in a timely manner. This consensus was arrived at following the 2015 outbreak of the Middle East Respiratory Syndrome. Thus, a law was enacted for an increase in the number of epidemic investigators, epidemic investigations of infectious diseases, acquisitions of information necessary for the epidemic investigations, and rapid disclosures of confirmed information. In addition, inter-institutional work performed within the legal system have been digitized and analysis functions have been automated, putting effort into the improvement of, and the efficiency in, the epidemic investigation. The Korea Centers for Disease Control and Prevention collects information according to the legal provisions and limitations, and utilizes the data through a security-verified system which will be checked for improvements on a periodic basis.

The EISS has been developed to secure, analyze and manage information needed for epidemic investigation within a month, which was made possible by the "Smart City Data Hub Construction Project" previously completed by the Ministry of Land, Infrastructure and Transport. Using the basis of the constructed engine as a platform to secure and analyze vast amounts of information needed to realize the creation and operation of a smart city, it was feasible to develop the EISS in order to process information regarding mobile phone locations and card usage in a modular manner.

Moreover, a security review process, which is essential for all computation systems built and operated by the country, was rapidly completed. Its rapid completion was immensely helpful in developing and running the EISS in a timely manner. Furthermore, security tests including mock attempts of hacking that required expertise, could be carried out prior to the platform's official operation. These tests could be considered as a foundation to lower the risk of personal information being leaked by hackers (and other similar means of obtaining the information illegally), allowing for greater confidence in applying the system's full scale.

Use of mobile phone data to prevent the spread of infectious diseases can be classified as a method which makes use of the information of mobile base stations as in the EISS. Other methods include the use of Global Positioning System (GPS) records stored within mobile phones, short-range wireless communication networks (such as Bluetooth), and those that use a combination of all these methods. The mobile base station has the largest range of error (about 0.2-2 km in radius, depending on the density of mobile base stations in urban and suburban areas), whereas GPS records of mobile phones can be tracked accurately with only a minor rate of error (20-30 m in radius). Since the relevant law in South Korea has stated that the access information (location information) to mobile base stations of mobile network companies is essential information for epidemic investigations, a personal agreement for the use of this information is not mandatory. However, it is considered necessary to obtain prior consent for future utilization of location information stored in personal mobile phones (in the form of GPS records); it is thought that this stored information required for epidemic investigations could be acquired retrospectively, if based on a clear legal provision.

Various methods of cellphone tracking are available for preventing the spread of COVID-19 and the relevant laws pertaining to these methods have enabled the "Private Kit: Safe Paths" application to be introduced [11]. Every 5 minutes, this application retrieves 48 days' worth of GPS information (as stored in the mobile phones of the application users) and automatically sends other users warnings that they may have come into contact with a confirmed COVID-19 case (after an application user has been identified as having a confirmed infection). In addition, Google and Apple, in collaboration with the European Union, have jointly developed the PEPP-PT (Pan-European Privacy-Preserving-Proximity Tracing) application which is a new method for tracking contacts using the access list between short-range wireless communication networks such as Bluetooth [12]. Relevant information (Bluetooth-accessed information by time period) secured by prior consent is sent to the central server after anonymization, which is then provided to other users whose time period and Bluetooth-accessed information overlapped, leading to self-isolation or testing for COVID-19. In this way, PEPP-PT can be used in the prevention of an epidemic.

Dr. Fraser of the Big Data Institute at Oxford University, UK, has presented a mathematical model which shows that the spread of COVID-19 would be effectively suppressed if over 50% of the population installed such applications (e.g. PEPP-PT) [13]. However, such methods are limited in that their actual effect on the prevention of an epidemic depends on the voluntary application installation rate.

Unlike applications which require installation by the public the EISS can be viewed as a support system for epidemic investigators. This system is used only as an auxiliary tool to rapidly track confirmed COVID-19 cases within legal constraints. In addition, it is only allowed to be used within the legally defined period of time (when an infectious disease is spread).

The EISS was developed in Korean to be used by Korean epidemiologists, but in the future, the preparation of a separate English version may be considered, but not at this time, as it may hinder the development and advancement of other functions in the EISS.

In the future, the EISS will be equipped with an information system that can legally obtain information including data regarding public transportation, medical institution visitation, and entry into and departure from the country, and will be upgraded into a system that can automatically receive the access information of mobile base stations from mobile network companies. In addition, the continuous development of the user interface as identified during the use of the system (by epidemic investigators) has also been planned.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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