Containing COVID-19 among 627,386 Persons Contacting with Diamond Princess Cruise Ship Passengers Disembarked in Taiwan: Big Data Analytics

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Abstract

Background: Low infection and case-fatality rate has been so far observed in Taiwan. One of major success is attributed to making a better use of big data analytics in efficient contacting tracing and management and surveillance of those who required quarantine and isolation.

Objective: We present here a unique application with big data analytics to Taiwanese people who contacted with more than 3,000 passengers disembarked at Keelung dock, Taiwan for one-day tour on Jan. 31, 2020, five days before the outbreak of COVID-19 on the Diamond Princess cruise ship on Feb. 5 2020 after an index case identified on Jan. 20th.

Methods: The smart contact tracing based mobile sensor data cross-validated by other big sensor surveillance data was used to identify 627,386 potential contact persons with the mobile geopositioning method and rapid analysis. Information on self-monitoring and self-quarantine was provided via short message service (SMS) message and SARS-CoV-2 test were offered for symptomatic contacts. National Health Insurance claimed big data were linked to follow up the outcome related to COVID-19 among those who were hospitalized due to pneumonia and advised to screen for SARS-CoV-2.

Results: As of Feb. 29, total 67 contacts who were had been tested by RT-PCR were all negative and no confirmed COVID-19 cases were found. Less respiratory syndrome cases and pneumonia also found after the follow-up of the contact population compared with the general population until Mar. 10.

Conclusions: Big data analytics with smart contact tracing, automated alert message for self-restriction, and the follow-up of the outcome related to COVID-19 using health insurance data could curtail the resources required for conventional epidemiological contact tracing.

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Low infection and case-fatality rate has been so far observed in Taiwan. One of major success is attributed to making a better use of big data analytics in efficient contacting tracing and management and surveillance of those who required quarantine and isolation.

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We present here a unique application with big data analytics to Taiwanese people who contacted with more than 3,000 passengers disembarked at Keelung dock, Taiwan for one-day tour on Jan. 31, 2020, five days before the outbreak of COVID-19 on the Diamond Princess cruise ship on Feb. 5 2020 after an index case identified on Jan. 20th.

Methods

The smart contact tracing based mobile sensor data cross-validated by other big sensor surveillance data was used to identify 627,386 potential contact persons with the mobile geopositioning method and rapid analysis. Information on self-monitoring and self-quarantine was provided via short message service (SMS) message and SARS-CoV-2 test were offered for symptomatic contacts. National Health Insurance claimed big data were linked to follow up the outcome related to COVID-19 among those who were hospitalized due to pneumonia and advised to screen for SARS-CoV-2.

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Big data analytics with smart contact tracing, automated alert message for self-restriction, and the follow-up of the outcome related to COVID-19 using health insurance data could curtail the resources required for conventional epidemiological contact tracing.

Keywords

COVID-19; Mobile geopositioning; Contact tracing; Big data

Introduction

Taiwan has been acclaimed for relatively low COVID-19 confirmed cases and case-fatality rates by its timely and fast response to COVID-19 pandemic [1]. Taiwan activated the Central Epidemic Command Center (CECC) for the COVID-19 outbreak after the first case was confirmed on Jan. 21, 2020 in Taiwan, and responsible for executing control policies, including border control, surveillance, quarantine, and resource allocation of preventing spread of COVID-19 in communities [2]. The crucial factor that renders these control measures successful is the comprehensive, precise and timely contact tracing to identify and manage the potential secondary cases and to interrupt further onward transmission. However, the conventional epidemiological contact tracing which relies on personal interviews is labor-intensive and time-consuming and may not be feasible when dealing with a pandemic with rapid propagation such as COVID-19 [3]. To enable more efficient and effective contact investigation, several digital databases such as electronic health records, phone-based global positioning system (GPS), card transaction, records, and closed-circuit television have been applied in South Korea [4]. Other contributory factor to contain the transmission is effective and efficient in quarantine, isolation, the surveillance of disease progression of COVID-19 after contact tracing. To achieve these two aims, a systematic and efficient big data method, using digital technology, sensor data, and claimed health insurance data may strengthen the conventional contact tracing and disease surveillance and inform the following control measures or mitigation plan. The scientific society in Taiwan thus calls for an innovative and integrated approach by making use of current digital technologies and big data on sensor and claimed health insurance to reach the aim of precision prevention for outbreak and surveillance of disease outcome among these contacts [5].

We here present a unique example of retrospectively investigating a substantial proportion of people contacting with the passengers of the Diamond Princess cruise ship, docked at the Keelung, Taiwan on Jan. 31, 2020, the mitigation plan using self-isolation and self-monitoring syndromes of COVID-19, and the disease surveillance of those contacts with an efficient big data analysis on the linkage of those contacts with national health insurance claimed data to ascertain COVID-19 and related respiratory syndrome. Considering the incubation period of SARS-CoV-2, the CECC decided to implement additional precautionary measures to further reduce the risk of importation of COVID-19 to Taiwan as the time the passengers lingering around Northern Taiwan is five days before the outbreak of COVID-19 reported from the Diamond Princess cruise ship at the Yokohama harboring on Feb. 5, 2020.

Methods

The first case who had returned from Wuhan to Taiwan was confirmed on Jan. 21, 2020 in Taiwan. After that, the central epidemic command center (CECC) was activated by Taiwan government to control the possible outbreak of COVID-19 [2]. The CECC is responsible for making and executing the policies including surveillance, border control, quarantine, and resource allocation and announced the highest level of alarm for preventing the outbreak of COVID-19 in Taiwan.

Although less than 20 cases were reported during the first COVID-19 epidemic period (from Jan. 21 to Feb. 9), the government has paid highly attention to all possible leak responsible for the transmission of COVID-19. The implementation strategies including border control, quarantine, and isolation. The first entry restriction on foreigners from pandemic areas, China in response to COVID-19 was initiated on Jan. 28, 2020. The government also kept watch on the cruise ships coming to Taiwan. These include a cruise ship, Diamond Princess, docked at the Keelung, Taiwan on Jan. 31, 2020. Considering the coronavirus incubation period, the CECC decided to implement additional precautionary measures to further reduce the risk of importation of COVID-19 to Taiwan when the outbreak of COVID-19 was reported from the Diamond Princess cruise ship at the Yokohama since it was harbored on Feb. 5, 2020. This unexpected event created a temporary public panic about community spread [6]. Comprehensive contact tracing and the mitigation plan could be one of strategies to minimize the spread of COVID-19.

Big Data Analytics for Containing the spread of SARS-COV-2

After knowing the outbreak of the Diamond Princess cruise ship on Feb. 5, 2020, the CECC immediately formed a task force to involve the preliminary investigation on Feb. 6, 2020. Contact tracing for those possibly contacted by already infected passengers was recommended. The design and process of contact investigation and management were elaborated as follows.

1. Big sensor data for the exploration of passengers' routes

As the cruise ship passengers had one-day excursion on Jan. 31, 2020 when the Diamond Princess cruise ship was docked at Keelung harbor, the team therefore designed the possible solutions for tracing their routes during itinerary in Taiwan. As it was impossible to conduct the retrospective individual interview for each passenger. The methods used to overcome the barrier of determining the location and itinerary of the contact are classified into four main categories including GPS in shuttle bus, credit card transaction log, CCTV, and mobile position data.

Among the four categories, the mobile geopositioning method was the mainstay here for identifying the passenger's routes by mobile position data for COVID-19 contact investigations that were able to provide the more accurate information on the location and the time of exposure. It can cope with the weakness of incomplete information while only using GPS by shuttle bus, card transactions, and CCTV as these three methods were only representative of partial passengers. They were used for the cross-validation for the routes estimated by the mobile sensors of the contacted persons in the light of mobile position data from the passengers.

The mobile position data from more than 3000 passengers on Jan. 31, 2020 were obtained from five local mobile phone companies. The contact locations were ascertained on the basis of the roaming signals with time of exposure over 30 minutes from multi-mobile base stations between 5:00 am and 20:00 pm that were recognized as the major tracking routes. Based on the mobile signal registered to the base stations of five domestic telecom operators, the first challenge is to recognize those 3000 passengers from all tourists in Keelung area. According to the record, the cruise was moored at the harbor from 6:00am to 6:00pm. We then checked the data between 1 hours before and 2 hours after the cruise at Keelung harbor. This will confirm the exactly mobile phone numbers travel with the cruise.

After collecting those phone numbers, the team depicted rough locations those phones appeared. Under the assistance from local government, it showed that about 34% of passengers took shuttle buses for local tours, 5.2% for taxi, the other were even biked or walked around at harbor or nearby area. More than 24 buses and 50 taxi had been interviewed and recorded. The estimated routes of passengers were further validated by the itineraries provided by travel agency. The team then checked the detail tour information for each route, interviewed with taxi drivers in harbor area for destination, and integrated all information to confirm more precisely location where passengers stayed.

The most important part of this stage is to identify the possible position where passengers were. This also showed how to utilize the big data analysis with a mixture of different data sources.

2. *Mobile sensor data for identifying the possible contacts*

At second stage, we resorted to the mobile position information of passengers above to identify the sensors of mobile from the possible contact persons. The citizens who carried the mobile phone and stayed within 500 meter of marked locations over 5 minutes were classified as the people who possibly contacted with the passengers of the Diamond Princess cruise ship on Jan. 31, 2020.

3. *Sending the messages on self-quarantine and self-monitoring to potential* contacts

On Feb. 7, 2020, CECC sent an alert notice using SMS through the Public Warning System to remind the contact persons of starting the mitigation plan. Namely, the potential contact persons were advised to be quarantine at home so as not to be engaged in public gathering for avoiding further contact. They were also notified to self-monitor COVID-19 compatible symptoms (fever, cough, and short of breath) and seek medical attention when symptoms developed.

4. *Management for potential contacts with symptoms*

On Feb 9, CECC sent a notice to all healthcare providers mentioning this event and the guidance for management for the potential contacts. Health care professionals were advised to perform SARS-CoV-2 testing for symptomatic contacts. After testing, symptomatic contacts may be hospitalized as indicated or return home for self-isolation. Health care professionals were also advised to proactively contact public health authorities to initiate active follow-up of the contacts.

5. *COVID-19 surveillance for contact population using national health insurance claims data*

In order to capture those in contact population who sought medical attention but did not report to public health authorities, we used the National Health Insurance claims data to track the health status of all subjects of potential contact. Those who were hospitalized due to pneumonia were identified. For those who remained hospitalized but had not tested for SARS-CoV-2, the healthcare providers would be informed of the potential exposure of the patient and screening for SARS-CoV-2 would be suggested.

Big data analysis for hospitalization of pneumonia without RT-PCR test for COVID-19 through national health insurance claimed data

As COVID-19 may also include few asymptomatic patients that may have long duration of disease process and were very difficult to be identified by RT-PCR test, it is also very interesting to compare the difference in rate of respiratory syndrome as well as the rate of pneumonia between the contact population (627,386 residents) and the general population in Taiwan (23,877,447 residents). Among these subjects, information on respiratory syndrome or pneumonia cases were ascertained by linkage with the big National Health Insurance claim database from Jan. 31, 2020 to Mar. 10, 2020. During this period, subjects with at least one outpatient visit with ICD-10 codes ("J00" to "J11") were identified as having respiratory syndrome. The subjects who had pneumonia were identified by ICD-10 codes ("J12-" to "J18").

Statistical Analysis

In order to evaluate whether there was significant increase in rate of respiratory syndrome as well as the rate of Pneumonia after sending the alert message in the route of passenger areas, we made comparisons in these rates between the contact population and the general population. The age standardized rates between the two groups were calculated. The Breslow and Day method was used to calculate 95% confidence intervals (CI) [7].

Results

Analysis and decision of digital contact tracing

Multiple means have been taken for contact tracing by the CECC. These included travelling itinerary arranged by agency, GPS in shuttle buses, credit card transaction log, CCTV and vehicle license plate recognition system, and mobile positioning data (Table 1). The pros and cons were delineated below.

1. Traveling Itinerary: The traveling itinerary proposed by travel agency delivered the information on schedule and the places of visit. However, this can only trace part of passengers. In addition, the specific time for visiting a place from itinerary sometimes is not reliable.
2. GPS in shuttle buses: GPS routes record in the shuttle buses have been considered. However, shuttle buses were used only by part of passengers. Others could travel by other transportations.
3. Credit card transaction log: The advantage of credit card transaction logs is the specificity on individual, time, and space. The difficulty is the accessibility of these data. Even it is doable, this dataset cannot trace those not using credit cards.
4. CCTV and vehicle license plate recognition system: To trace the routes of shuttle buses or private transportations, CCTV can target at specific vehicle or passenger. However, the coverage of CCTV is not hundred percent. Besides, the large number of passengers makes the tracing with CCTV and license plate recognition impossible.
5. Highway electronic toll collection (ETC) system: All vehicles passing the national freeways were checked with the electronic toll collection system in Taiwan. It can trace specific person or vehicle, but not feasible when the number of passengers was large.
6. Mobile positioning data: Passengers travelling with mobile phone can be traced with mobile positioning service for specific time and space. In addition, the same information can be applied to delivering the warning message for citizens who were potential of being contacted. However, this way has the potential to miss those without carrying a mobile phone but it is very rare in

Taiwan.

Finally, considering the specificity, feasibility, and the largest coverage of passengers, the CECC made a final decision to apply mobile positioning data for contact tracing and the delivery of alert message. It should be noted that other methods, except the credit card transaction due to privacy concern, have been used for cross validation.

The routes of passengers from Diamond Princess cruise ship and contact tracing

Figure 1 shows the traveler's routes while passengers got off the cruise. Based on the estimated routes, the 39 marked locations were identified on the map list as shown in Figure 2. Most of the warning locations are famous sight-seeing visiting areas in northern Taiwan.

The corresponding possible contact persons were 627,386 subjects based on the mobile position information. The symptom monitoring and self-quarantine message was sent though SMS after identifying the contact person on Feb. 7, 2020. The alert message (Figure 3(A)) is as follows:

"*Due to the COVID-19 epidemic, anyone who had been to the following locations from 6 a.m. to 5:30 p.m. on Jan. 31, please conduct symptom monitoring and self-quarantine and isolation until Feb. 14. If you need any assistance please call 1922 hotline.*"

The specification of the locations can be revealed at the website *(http://bit.ly/2SpSxeT)* (Figure 3(B)) via SMS message. As of the end of Mar, it has been visited 29,317,172 times.

RT-PCR test for those with suspected symptoms and signs notified through the alert message

As of Feb 14, CECC were notified of 20 symptomatic contacts who followed the guidance on the alert message and thus sought medical care. All received COVID-19 testing and all tested negative.

COVID-19 surveillance for the contact population through national health insurance claims data

As of Feb. 29, a total of 121 hospitalizations due to pneumonia were identified among the contact population. Twenty-four contact-patients had been reported as suspected COVID-19 cases and all tested negative. Among 41 contact-patients who remained hospitalized, 23 received testing for COVID-19 and all showed negative results.

Disease surveillance of respiratory syndrome and pneumonia for the contact population through big health insurance claimed data

During the surveillance period between Jan. 31 and Mar. 10, the age-standardized rate of respiratory syndrome (16.87 per 1000) in the contact population was lower than the general population (19.23 per 1000) (Table 2). We found the age-standardized relative ratio of 0.929 (95% CI 0.923-0.935) for the contact population diagnosed as having respiratory syndrome, relative to the general population. Similarly, there was a lower risk for Pneumonia among the contact population compared with the general population (age-standardized relative ratio 0.915 (95% CI 0.869-0.963)). This suggests that smart contract tracing with mobile position data followed by self-quarantine and isolation may be a useful means of preventing the spread of COVID-19.

Discussion

Although the public health interventions aimed at reduction population contact rates have demonstrated its efficacy in the containment of pandemic [8,9], its implementation is involved with great impact for subjects, the community, and the public health system in contemporary democratic society [10]. The manpower and work-load for quarantine of infectious disease are usually highly demanded. When facing the global crisis of an emerging infectious diseases such as COVID-19, rapid response and immediate interventions for preventing the outbreak are essential. Smart contact tracing with big sensor data on mobile position data and its connected mobile phone can provide information in a timely manner and help crisis management under such a situation. In this study, we demonstrated how smart contact tracing can be applied to the contact history between Taiwanese people and the possible infected tourists of the passengers disembarking from the Diamond Princess cruise ship nearly before the outbreak of COVID-19 on this cruise ship.

In order to rapidly trace the potential contacts, the numerous locations where the cruise ship travelers may have visited were identified by passive mobile positioning data firstly. The passive mobile positioning data handovers in network cells that stored the location of call activities in mobile service providers. This data offers good potential not only for the monitoring of the mobility of the tourist group but also for the identifying of the people in contact with the tour group. This mobile geopositioning method had also been used in a mHealth study to measure human mobility, disease connectivity and health risk in travelers [11].

Based on our mobility and geography of mobile position analysis, total of 627,386 citizens had been possibly exposed to passengers on Diamond Princess cruise. These persons were sent a syndrome monitoring and self-quarantine information via SMS messaging to their phones for mitigating the possible community spread. Although the contact persons per traveler over 190 might not be realistic, enlarged the targeted contact population with no harm was acceptable while against COVID-19 spread was an emergency situation. Moreover, it should be noted that providing accurate, timely information for decision making is crucial during the crisis. It had been a few days when the exposure of infected hosts had occurred. The contact tracing and management using information technology had to be quickly implemented without delay. This is one of the advantages of using big data technology for helping analysis. In terms of fighting against COVID-19, the similar big data technologies have been also applied in the spatial tracking of the patient for tracking virus transmission and potential spatiotemporal exposure to support the epidemiological investigation with rapid analysis [12].

For evaluation the impact of self-quarantine at home policy with alert message, no confirmed COVID-19 cases in this contact population was ascertained. In addition, we also used the national health insurance claimed database to facilitate another big data analyzing in surveillance of severe respiratory symptoms. The lower risk of mild or severe respiratory symptom was noted in the exposed group (contact population) compared with the unexposed group. In addition to the prevention of the spread of SARS-COV-2, this may be attributed to the enhanced awareness of his/her own health status and the enhanced personal self-contained life style affected by alert message.

From the perspective view of big data technology, this study revealed the mobile geopositioning method through big data technology, which achieved geographic route acquisition and mapping mobile positioning from mobility of population nearby to conduct contact tracing. The analysis platform was quickly constructed through an innovative technology system to support the timely epidemic analysis.

More importantly, it is expected that smart contact tracing with big sensor data analysis applied to contact investigation of those who may be contracted by is also cost-effective because the costs and manpower would be substantially reduced if the conventional epidemiological contact investigation method is used.

There is a major limitation. The potential contact persons identified in the current study tended to include more working populations and students because those who have no mobile phone are more likely to be very young or the elderly people who are hard to be traced by this smart contact tracing technology. This weakness may be tackled by providing active surveillance system for them to contact local health authority.

In conclusion, the successful prevention the community spread of COVID-19 in the crisis of contact from potential infected travelers of the Diamond Princess cruise ship by using big data analytic has been demonstrated. This is an example of how a big data technology can be applied in contract tracing and quarantine to support the epidemiological surveillance of new virus infection.

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Authors' Contributions

CM Chen and CC Chan contributed to the study concept and design. HW Jyan, SC Chien, PC Lee, CF Lee, YT Yang, and MY Chen contributed to the acquisition of data. HH Jen and CY Hsu contributed to the statistical analysis. LS Chen and HH Chen contributed to the interpretation of results. CM Chen drafted the manuscript. All authors gave final approval of the manuscript.

Conflicts of Interest

None

Abbreviations

COVID-19: coronavirus disease

SMS: short message service

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2

WHO: World Health Organization

CECC: Central Epidemic Command Center

GPS : global positioning system

CCTV: Closed-Circuit Television

ICD-10: The International Statistical Classification of Diseases and Related Health Problems 10th Revision

ETC: electronic toll collection

CI: confidence intervals

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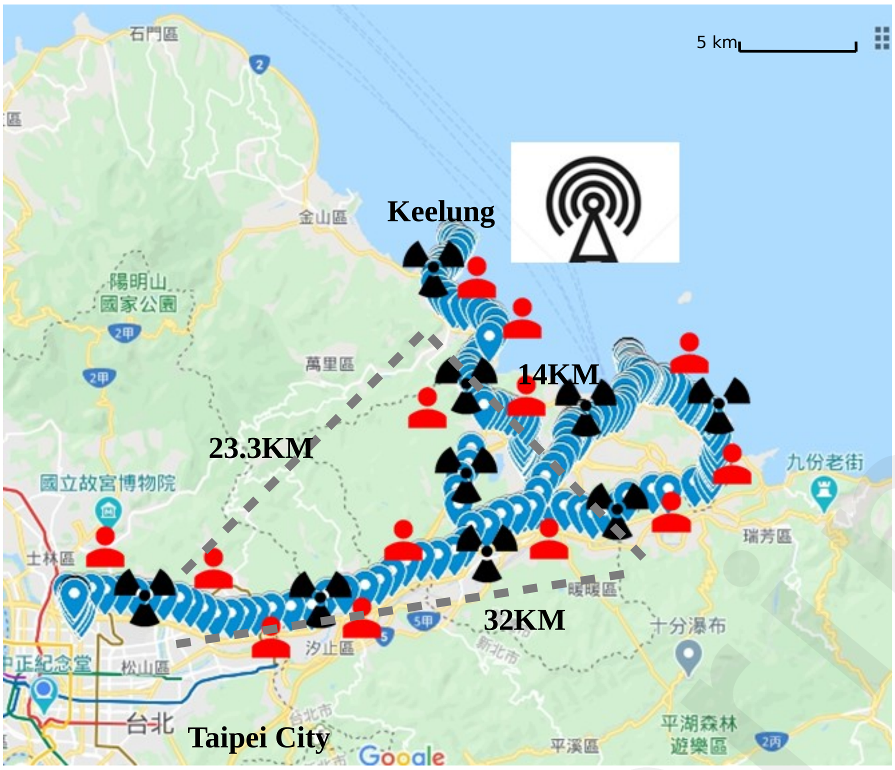
Table 1 Potential means of contact tracing for passengers from Diamond Princess Cruise ship during the one-day Taiwan tour

Digital Records	**Investigation**	**Difficulties**
Travelling guide provided by agency	To trace the travelling routes	• Cannot trace those travelling with taxies or independent of agency • Cannot identify the exact visiting time
Global Positioning System in buses	To trace locations where buses drove through	• Cannot trace those travelling with taxies or independent of agency
Transaction of credit cards	To trace the travelling routes by shopping records	• Not all passengers using credit cards
CCTV and recognition system of vehicle license plates	Travelling routes	• Large number of passengers • Depending on CCTV location • Time consumption
Electronic Toll Collection System on the nationwide freeways	To trace location where buses drove through	• Available in limited routes
Mobile phone positioning system	To trace individual-based travelling route	• Only applicable to those using roaming service for mobile phone

Table 2. Respiratory syndrome/Pneumonia cases, rates and relative ratios in exposed group and unexposed group.

Diseases	**Exposed Group**	**Unexposed Group**
	N=627,386	N=23,877,447
Respiratory syndrome		
Cases (%)	105,837 (16.87%)	4,592,694 (19.23%)
Expected Cases	113,920	-
Crude relative ratio	0.877 (0.872-0.882)	1.00
Age-standardized relative ratio	0.929 (0.923-0.935)	1.00
Pneumonia		
Cases (%)	1,479 (0.236%)	91,066 (0.381%)
Expected Cases	1,616	-
Crude relative ratio	0.618 (0.587-0.651)	1.00
Age-standardized relative ratio	0.915 (0.869-0.963)	1.00

Figure 1. Passenger's routes of one-day tour on Jan. 31, 2020 in Taiwan

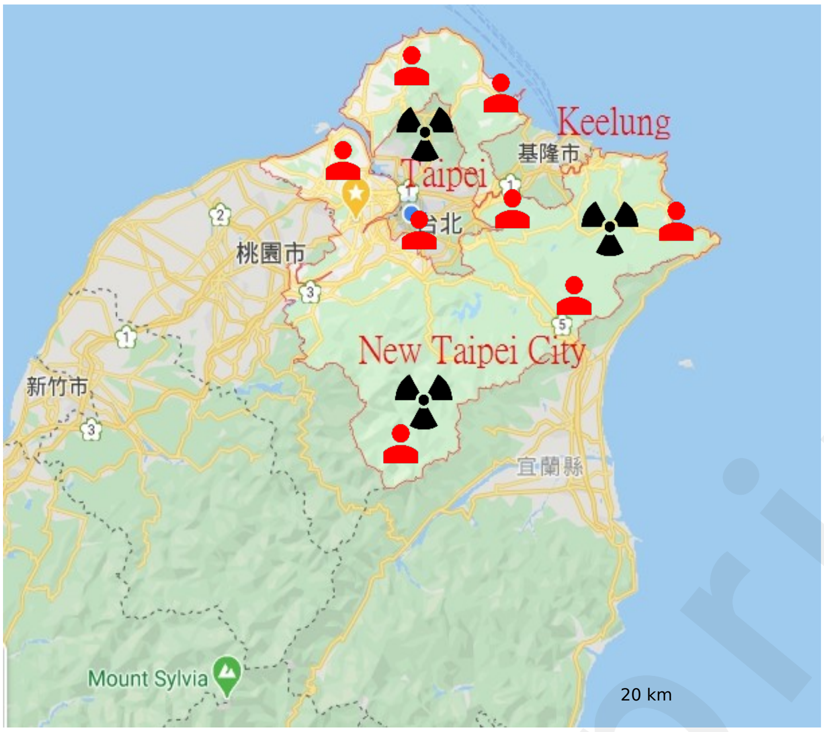


Mobile phone base station

Contact people

Traveler's route

Figure 2. The tagged locations based on routes of passengers in three cities (Keelung, New Taipei City, and Taipei) for broadcasting the warming message



Tagged locations:

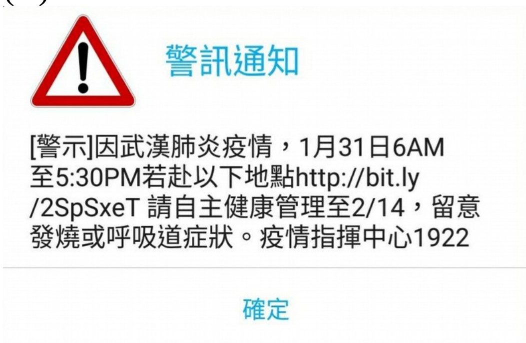
Keelung: Keelung Waimu Mountain, Keelung Zhongzheng Park, Keelung Cultural Center, Xiandong, Keelung, Zhengbin Fishing Port, Keelung Peace Island, Keelung Harbor, Miaokou Night Market, White Rice Fortress, Keelung, Diaohe St., Zhongzheng Dist., Keelung City,

New Taipei City: Shifen Old Street, Jiufen, Shifen Waterfall, New Taipei City, Yehliu Geopark, NanYa Wonderful Rock, Ruifang District, New Taipei City, Turtle Roar, Wanli District, Bisha Fishing Harbor,

Taipei City: Nanmen Market, National Revolutionary Martyrs' Shrine, Jhungshan Auditorium, National Chiang Kai-shek Memorial Hall, Taipei, Confucius Temple, Liberty Square Taipei, Ximending, Section 4, Zhongxiao East Road, Taipei City, Dalongdong Bao'an Temple, National Palace Museum, Dihua Street, Zhuzihu, Yangmingshan, The Grand Hotel Taipei, Xichang Street: Herb Lane, Lungshan Temple, Taipei Main Station, Pacific Sogo(Fuxing), Taipei.

Figure 3. A demonstration of (A) alert message and (B) contact locations integrated with google map (http://bit.ly/2SpSxeT)

(A)



(B)