DYNAMIC ORIGIN-DESTINATION AND FLOW ANALYSIS OF THE DISASTER IMPACT ZONE

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Abstract: This paper discusses the critical role of using mobile information to depict the evacuation process in the disaster impact zone. Many of the deaths and property losses could be prevented if better information is available, especially people mobility patterns and their behavior in particular hazard zones. Increasingly, this information is becoming available with the help of technologies such as satellite-based positioning technologies and the penetration of the mobile phones. This new type of mobile phone service, called mobile auto GPS, has been used to provide anonymous set of millions of user trajectory from August 2010 to July 1011. The event of the 2011 Great East Japan Earthquake had been observed in this study. We applied spatial-temporal analysis method associated with disastrous events to illustrate the evacuation process in the emergency. The results offer considerable detail measurement of individual location in very fine temporal scale and show the estimation of origin-destination of people in disaster impact zone. The flow analysis can also be visualized in near real time to help decision makers develop and revise the evacuation plans.

1. INTRODUCTION

The march 11 Tohoku earthquake is one the most powerful known earthquake ever to have hit Japan, and one of the five most powerful earthquakes in the world since modern record keeping began in 1900 (USGS, 2011). In this paper, the location of million of mobile phone users of pre and post earthquake event had been anonymously captured and analyzed to illustrate the potential use of this new dataset for emergency preparedness and response.

In general, the crisis management plan is designed to maximize human survival, preservation of property and minimize danger. A crisis may be sudden and unforeseen, for instance earthquake and tsunami, and there may be varying periods of warning. For the pre-disaster management, the evacuation plan is prepared and intended to be sufficiently flexible to accommodate contingencies of all types, magnitudes and durations. Most of the evacuation planning utilizes the origin-designation (OD) flow optimization problem, in which seeking an optimal allocation of lane reversals across an evacuation network (Xie et al., 2011). However, considering emergency transportation available in the real situation, it is difficult to obtain the current network condition. This is because the assessment of network reliability following natural disasters is a complex issue that involves several physical and functional factors, which are not necessarily independent. (Giovinazzi and Nicholson, 2010) Moreover, identification of emergency shelters and number of refugee by location are extremely important but difficult to confirm at the early stage of the disaster event. This problem is normally undetectable unless we have details information of people mobility.

This research aims to introduce a novel dataset acquired through typical mobile phone infrastructure, as well as provides real potential use of mobile GPS in practical manner. The analysis of this new dataset gives us a hint on how to utilize this dataset for disaster response with a particular focus on the role of human participatory sensing, data acquisition and distribution.

The rest of the paper is organized as follows: In section 2 we describe the recent works of using information and communications technology (ICT) for emergency response, Section 3 introduces the data source and its limitation, Section 4 discusses the potential use of mobile GPS for disaster response and the methods to generate the dynamic OD from this data source following with conclusions in section 5.

2. RELATED WORK

In the event of a crisis such as a big earthquake, the Government needs to be prepared to provide a swift and appropriate response. In the absence of a well-thought plan, the city can instantly turned into a catastrophic mess. Emergency responders had to know where the people most in need were located and how to get assistance and relief to them. Zook et al. (2010) outlined some of the ways in which information technologies (ITs) were used in the Haiti relief effort. It represents a remarkable example of the power of crowd sourced online mapping and the potential for new avenues of interaction between physically distant places. Laituri and Kodrich (2008) mentioned about the development of "people as sensors". The authors examined the contribution from the public via the Internet to collect information about their locality and disseminate to those in need, also the future potential of using geospatial technologies such as GIS, RS, GPS and the Internet for disaster preparedness, response, recovery and mitigation.

In the recent year, responses to disasters have changed to more mobile-related ICT infrastructure and allow citizen to be a part of the system. Movement of people, present location and their behavior during the crisis are undoubtedly the most information needed by decision makers. With the high penetration rate of mobile phone subscribers today, it helps provide accurate sources of people location information to support the emergency management. Tracking of human flow by using proxy location of cell phone devices is one of the most powerful sources to record real time national-wide people's movement. To derive the OD matrices, Francesco et al. (2011), introduced an algorithm to analyze opportunistically collected mobile phone location data to estimate dynamic OD matrices. The authors estimate weekday and weekend travel patterns of a large metropolitan area. The methodology can capture fine-grained OD matrices in both spatial and temporal scale, especially during special events. The above concept has been discussed and further explored by Frias-Martinez et al. (2012) and Ma et al. (2012).

Difference form this previous research that using mobile phone call detail record (CDR) for the OD retrieval, our current works estimate the OD in more fine-grained spatial and temporal manner. The mobile auto GPS has been operated for the first time by the mobile operator and has been used nationwide from 2009. This paper examines the dynamic OD extraction algorithm and demonstrates the use case to outline the emergency evacuation procedures during the great earthquake in Japan.

3. DATA SOURCE

The data we used in this study is anonymously collected from the mobile auto GPS services achieved by Zenrin Data Com Inc.(ZDC). The service exploits the fact that a mobile terminal moves from place to place together with the users. This approach enables the provision of behavior-support services that are closely linked with the user's individual behavior. Technically, the mobile auto GPS enabled handset position is measured every 5 minutes, the information is then sent through the network to perform specific analysis and provide services for the registered users. To reduce battery consumption, the accelerometer is used to detect the movement of mobile phone and it deactivates GPS acquisition and sending function if there is no movement. In total, about 1.6 million users are contributed the localized data during one year period. (Aug 2010 – July 2011). Table 1 shows the sample dataset that naturally in a fully anonymous process without identifying the personal identity. Six of attributes are provided including the user id, timestamp, latitude, longitude, estimate error and altitude.

Table 1: A sample of mobile GPS dataset

UID	Time	Latitude	Longitude	Error	Altitude
00862690	2010-08-01 12:01:09	34.69888	135.534146	1	64
00862754	2010-08-01 21:10:13	39.703028	141.146445	2	176.94
00886354	2010-08-01 12:48:23	34.33872	135.600167	3	165.73
00862690	2010-08-01 14:46:09	34.709877	135.591781	1	64
00169966	2010-08-01 18:19:52	35.534478	140.304336	3	39.64
00169966	2010-08-01 18:24:52	35.527892	140.312319	3	17.83

There are some known issues of this dataset, as the mobile auto GPS data comes from a service provided by a mobile phone operator, hence the subscribers has a freedom to stop the service anytime. Every user is not expected to continue to contribute their GPS points for the entire period of one year. Another issue is the dataset only reflect to a certain percentage of the population of one mobile phone operator in Japan.

4. DYNAMIC ORIGIN-DESTINATION AND FLOW ANALYSIS

In this analysis, we highlight the evacuation process of one of the most critical zone during the crisis. The Fukushima Daiichi nuclear power plant (DNPP) was flattened by the tsunami, which struck the area within an hour after the big quake. By the early time of evacuation period, it was not even known where most of the evacuees were. The local government in Fukushima said they didn't know where 40 percent of the residents around the Fukushima DNPP went. Evacuation is the primary protective action utilized in catastrophic disasters and remains a major emergency management strategy. Real-time monitoring of people movement in disaster areas is crucially important to develop and revise an evacuation plan.

By mean of tracking people, mobile phone is an ideal tool to capture their movement in wide area. We implemented spatial-temporal data mining techniques to estimate the usual home location of the people at the impact zone. The evacuation process can also be observed and updated in short period, for instance, to retrieve the daily movement of the refugees. We validate the reliability of this dataset by comparing the estimated home location result, which will be described in the next section, with the population census statistic from the Establishment and Enterprise Census data (2006) of the Ministry of Internal and Communications. This estimation approach turned out to be fairly reasonable as the result of the estimated home locations was comparable against the population density. (Figure 1)

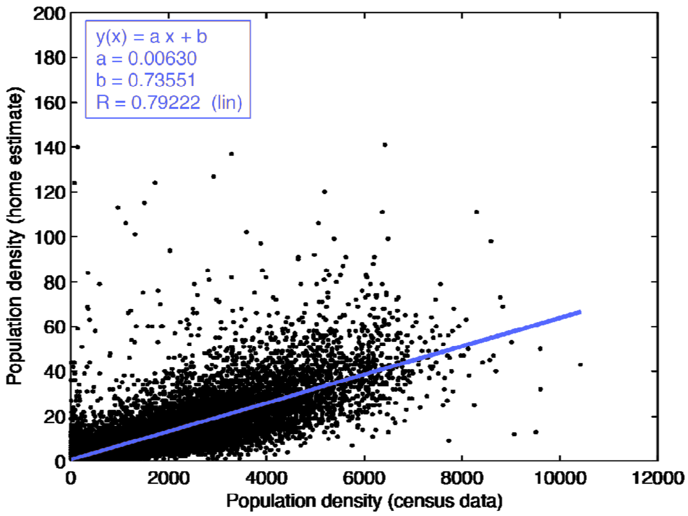

Figure 1: Comparison of the estimate home location against the census data counting in 1-kilometer grid size.

4.1 Home location Extraction

Most human are routine and tend to spend time in same places in their daily life. GPS points represent spatio-temporal location of people defined by $P = (p_1, p_2, \ldots p_n)$ where p = (id, time, lat, lon) and n = a total number of points. Connecting consecutive points of a user a day according their time series, user trajectory can be obtained. To extract the home location, we first apply stay point extraction algorithm (Montoliu et al., 2012) based on the spatial and temporal values of points. In this method, a stay point represents a geographic region, which a user stays within the distance and time threshold factor. Space distance and time difference between observed points are applied as criteria for detecting stay points (Figure 2). In this calculation, a stay point is detected if individual mobile phone users stay more than 20 minutes within the distance of 200 meters.

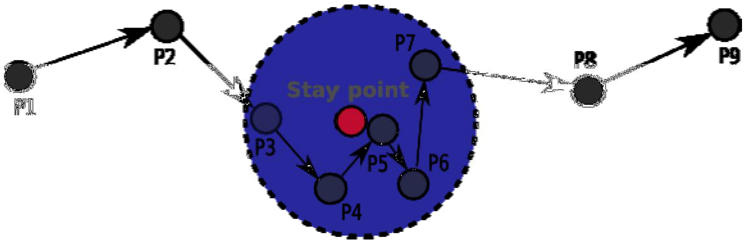

Figure 2: Capture of the stay points of individual GPS trajectory.

The latitude and longitude of a stay point is a centroid of all points in a stay area. Daily stay points of user are combined together and used as an input for k-means clustering algorithm. The result clusters represent the long-term significant places of each individual. By analyzing 6 months period of the stay points before March 11 using time factor, home location of each individual can be derived. The result is validated against the census statistic data as shown in Figure 1.

4.2 Origin-destination Matrices

Theoretically, monitoring of the evacuation activity can be performed in near real time or in daily basis. Using the same assumption and methodology, daily home location after the earthquake can be detected. The evacuation process of refugees in the disaster zone can also be observed by estimating the city-level OD matrices.

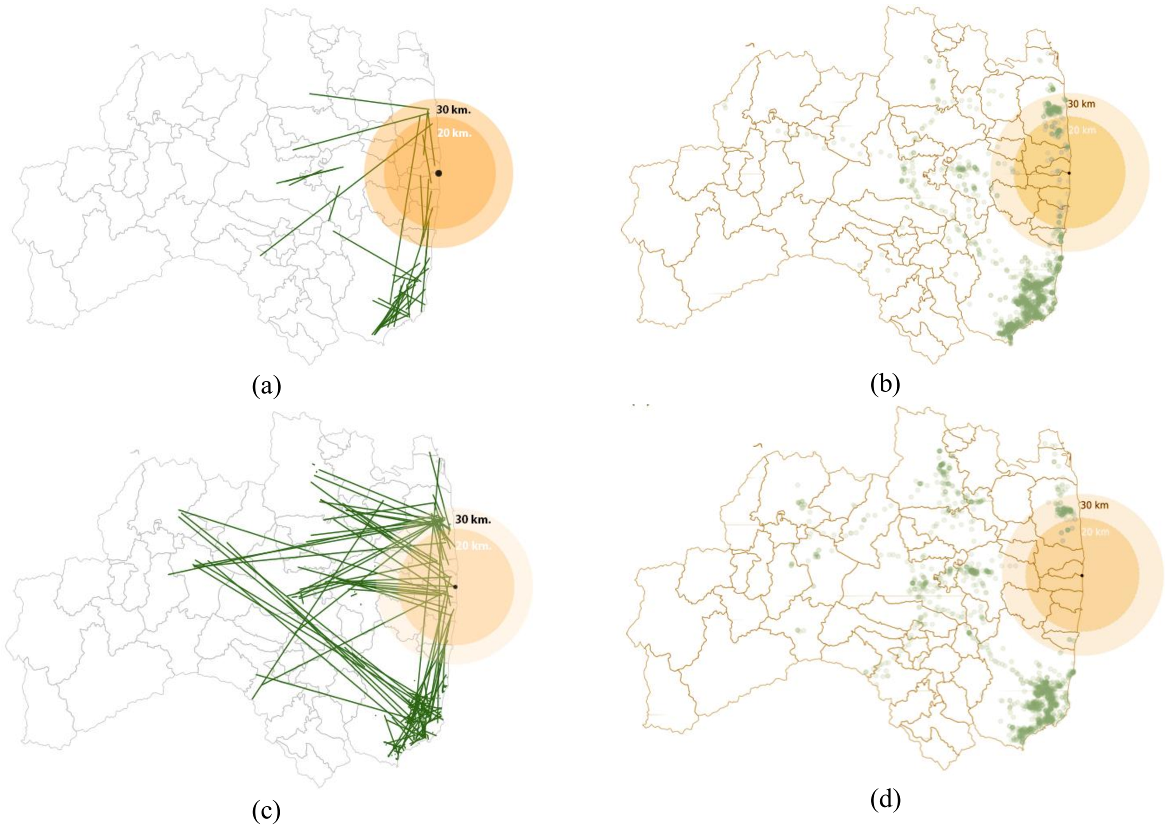

Figure 3: Capture of daily OD from the restricted area (20 km.) and evacuation prepared area (30 km.) around the Fukushima Daiichi nuclear power plant (DNPP). (a) Illustrates the OD on March 12, (b) illustrates the population density on March12, (c) illustrates the OD on Mar 14 and (d) illustrates the population density on March14.

Figure 3 shows the origin-destination path of people who live in the cities associated with evacuation-prepared area. It clearly identifies the evacuation processes on March 12 and March 14, the day after the massive explosion in the outer structure of the power plant unit 1 and unit 3. The Japanese government suddenly declared a 20 km zone around Fukushima Daiichi as an evacuation zone on March 12 and most of the people in the restricted area left there home by the night of March 14.

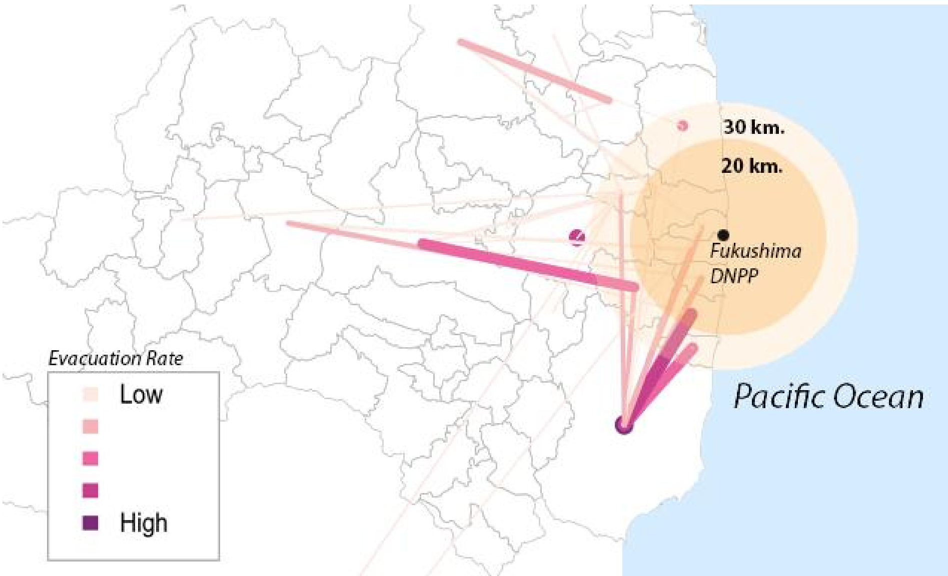

Figure 4: Estimating of first month real evacuation scenario and origin-destination route of refugees from the restricted area of Fukushima Daiichi nuclear power plant (DNPP).

After 21 April 2011, the Japanese government restricted a 20 km zone around Fukushima Daiichi as a "no-go" zone, and threatened anyone who entered or remained in the zone with arrest or detention and fines. The order affected 80,000 residents who live in the restricted area (Japan Times, 2011). Figure 4 illustrates the origin and destination city of evacuees during the first month from the Fukushima DNPP restricted area. To give a clear image, only the destination city where evacuation ratio is greater than 5 percent are plotted on the map. Table 2 explains the estimate evacuation ratio at the city/town level.

Table 2: A sample of estimate evacuees from the restricted area to the shelter provided area

Home	Evacuation To	Prefecture	Ratio (%)
Naraha-machi	Koriyama-shi	Fukushima	11.54
Naraha-machi	Iwaki-shi	Fukushima	61.54
Tomioka-machi	Koriyama-shi	Fukushima	11.9
Tomioka-machi	Iwaki-shi	Fukushima	32.14
Okuma-machi	Aizuwakamatsu-shi	Fukushima	17.65
Okuma-machi	Iwaki-shi	Fukushima	29.41
Futaba-machi	Fukushima-shi	Fukushima	6.67
Futaba-machi	Iwaki-shi	Fukushima	23.33
Futaba-machi	Kazo-shi	Saitama	10
Namie-machi	Fukushima-shi	Fukushima	14.85
Namie-machi	Koriyama-shi	Fukushima	12.87
Namie-machi	Iwaki-shi	Fukushima	15.84

5. CONCLUSIONS AND DISCUSSIONS

In this paper, we estimated the origin home location and evacuation destination of people in the restricted area of Fukushima NDPP using the new source of data from mobile GPS services. The evacuation analysis after the great Japan earthquake and Tsunami on March 11, 2011 was conducted and demonstrated as a proof of concept to support the emergency-response system. A combined high temporal and high spatial resolutions of GPS-enabled mobile phones data give decision makers more efficient and cost effective way to observed evacuation process in a timely manner.

As of September 2011, more than 100,000 Fukushima Prefecture residents are still subject to a range of evacuation measures, forcing them to live outside their home cities and towns. Some locations near the crippled nuclear power plant are estimated to be contaminated with accumulated radiation doses of more than 500 millisieverts a year, diminishing residents' hopes of returning home anytime soon. (Mainichi, 2011). Again, to cope with long-term evacuation and recovery process, the GPS-enabled mobile phones can potentially provide an exhaustive spatial and temporal coverage with more accurate location information, and thus more accurate estimation of the total number of evacuees in each specific area.

Finally, note that the estimation result in this article with spatiotemporal threshold function and clustering techniques can actually provide meaningful origin-destination statistics and visualizations during these catastrophic disasters. Therefore, the potential errors, inaccuracies, and/or biases observed in the data have to be addressed and compared with the official statistic data that we may obtain in the future.

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