An IT Logistics Management Plan for Disposal of Large-Scale Earthquake Wastes: Case Study of Koto-Delta Region, Tokyo

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Abstract: Rubble disposal is one of the most important issues for urban restoration after an earthquake disaster. A detailed management plan is required to deal with the rubble generated, especially by a large-scale earthquake, in order to avoid undesirable effects such as traffic congestion and safety issues. This paper proposes an IT based logistics system to manage the disposal of rubble. A specific management plan is suggested for the area of Koto-Delta region, Tokyo. The plan includes an operation procedure, specifying locations of stock yards for rubble disposal. A simulation is used to estimate selected air quality impacts caused by the operation.

Key Words: Logistics, Disaster, Rubble, Disposal, Earthquake Waste

1. INTRODUCTION

The southern part of Hyogo Prefecture, Japan suffered a large-scale earthquake, the South Hyogo Earthquake, in 1995, causing more than 6,300 deaths. In addition, 110,000 buildings were damaged along with infrastructure including railways and roads. In addition, the damage extended to the nationwide economy as the overall cost was estimated to be 10 trillion Yen ($102.5 billion), which was 20 percent of the annual budget of the Japanese Government (Kobayashi, 1995). This catastrophe was named the Hanshin-Awaji Earthquake Disaster. This earthquake caused Japan to implement new measures to cope with the numerous problems encountered after the disaster. One of those measures is the restoration plan (Ota et al, 2008). Two months after the earthquake, the Government of Hyogo Prefecture issued a plan for urban recovery, which became the nationwide standard for post-disaster recovery plans (Kondo, 2008).
One important task in the recovery program is inevitably to remove the rubble generated by the collapsed buildings and infrastructures. The huge volume of rubble delayed the restoration of urban areas. As well as a prompt rescue operation, a quick removal of rubble from the affected area is desirable for faster redevelopment. However, it is not an easy task without a proper management plan. Unfortunately, this issue did not receive enough attention at the time. After the Hanshin-Awaji Earthquake Disaster, the cities in the southern part of Hyogo Prefecture were struggling with the problem since there was no rubble management plan; and consequently most of the rubble was used as materials for reclamation works at the seashore in the vicinity (Irie, 1995). However, the choice of land reclamation is not always possible, and so it is very important to determine in advance the best places for storage of the rubble. Thus, a plan to manage the removal of the rubble must be included in the city’s post-disaster restoration and redevelopment project. The rubble management plan should take into account issues of traffic management, transportation networks, and the rubble transportation routes, in order to speed up restoration of the region after a disaster and, at the same time, to reduce disturbances from the operation to the citizens.

Information technology plays an important role in modern life. Real-time technology such as car navigation systems, incident warnings, and forecasting systems have become commonplace. Moreover, these technologies have recently become more mobile, often available as handheld devices. Some IT technology has been used for disaster prevention purposes; GIS technology especially, has been widely used as a supporting tool in disaster recovery plans such as the work of Zerger and Smith (2003). Mobile phones and car navigators have become useful tools for gathering information in a disaster situation.

This paper therefore proposes an IT based logistics management plan to dispose the rubble generated by a large-scale disaster. On the one hand, the problems related to traffic management in the aftermath of the Hanshin-Awaji Earthquake Disaster are analyzed. Among the most important problems are the difficulty of gathering data to ascertain the scope of damage in each region, and the lack of a management plan to guide the response to the disaster, resulting in avoidable severe traffic congestion. On the other hand, this paper proposes a system for gathering information and a rubble transport management system in a scenario assuming that a large-scale earthquake affects the Tokyo Region. A combination of technologies, including GIS, Traffic and Road Information Systems, and CCTV cameras, are proposed to be used in order to maximize the capacity to gather the best information on the damage caused. With GIS, the amount of the rubble is estimated based on information such as the size, the location, and the age of the buildings and infrastructure. The proposed logistics system is the combination of these technologies to increase the efficiency of the operation.

The experiences and the problems related to the rubble disposal from the Hanshin-Awaji earthquake are presented in the next section. In addition, the plan to manage the rubble for Koto-ward of the Tokyo region is discussed. Later, technologies useful for disaster prevention and rubble disposal management are summarized in Section 3. Section 4 presents the proposed management system for rubble disposal using the discussed technologies. In Section 5, this paper presents estimates of selected air quality impacts resulting from two simulations of transporting rubble 1) by dump truck only and 2) by a combination of dump trucks and ships. Finally, the last section summarizes and provides recommendations for subsequent studies.
2. RUBBLE DISPOSAL METHOD

2.1 Experiences from the Hanshin-Awaji Earthquake

After the earthquake, the government planned to dispose of the rubble within a year, beginning in the middle of 1995. New measures were adopted to speed up the operation. The measure was the dismantling and recycling of the rubble. Rubble was not only stored in temporary stock yards but also was used, for the first time, to reclaim land, in Osaka bay (the so-called the PHOENIX project (The Website of Osaka City Environment Bureau, 2011). The amount of rubble generated by the earthquake was 20 million tons in total, where 14.5 million tons were from dwellings, 4.8 million tons from infrastructures, and the remaining 0.7 million tons from public housing (Hyogo-Prefecture Governor’s Policy for Disaster Prevention Division, 1996).

Figure 1 shows the disposal method of the rubble. The rubble was divided into two types: combustible and incombustible. Both types were recycled or used for reclamation where possible. Residual combustible material was burnt.

Several problems arose during the recovery and rubble disposal process after the earthquake. Some suggestions to better cope with the problem, based on the experience of the Hanshin-Awaji Earthquake, are listed as follows (Japan Dredging and Reclamation Engineering Association, 1996):

1. **Sufficient coordination among different authorities.**

Normally municipal authorities are in charge of garbage disposal in the designated region; however, the city of Kobe alone was responsible for all the rubble in the affected region after the earthquake. Due to administrative issues, when one municipal authority was authorized to take charge of operations, it became difficult for the other municipalities to be fully involved. Responsibility for rubble disposal should not be given only to one municipal authority; there should be a management plan to organize cooperation with other municipalities. As well as coordination among municipalities, it is suggested that strong cooperation between the public and private sectors be encouraged.
(2) Management plan for dismantling rubble

After 4 months, dismantling of collapsed houses was only one third finished. Assuming the same working speed, complete disposal would take up to a year. One reason was the severe traffic congestion caused by vehicles used for the works. The efficiency of dismantling buildings would be facilitated by management plan identification of spaces for temporary stock yards as immediate places for setting up the working machines.

(3) Preservation the delivery routes

Many roads were destroyed by the earthquake causing severe traffic disruption, such that it became difficult for large vehicles to move. This blockage was one of the main causes of delay in the operation. At that time, the operation was done more smoothly due to cooperation with the police of Hyoko Prefecture who gave priority to the disposal vehicles over other traffic. In addition, water transport contributed significantly by carrying a large amount of rubble. A suggestion for the delivery routes is to preserve two traffic lanes of the designated roads for emergency uses. The preserved routes should be different from the routes used for normal garbage disposal.

(4) Requirement for temporary stock yards

Rubble, once dismantled, should have a designated location for further processes such as material classification, crushing and so forth. As well as designated locations for dismantled rubble, there should be places for storing the rubble, for material classification, and for the storage of materials after separation, such as concrete and wood for recycling. In the case of the Hanshin-Awaji earthquake, many reclaimed areas have remained unused and there are some unfinished reclamation works using the recycled materials such as some places that were part of the Phoenix project (Japan Dredging and Reclamation Engineering Association, 1996). It is suggested to plan in advance suitable locations for reclamation. In addition, since there are many stages in the recycling process, the excessive use of temporary stock yards should be avoided. Consolidating the entire recycling process in a single location would reduce the total amount of transportation required.

(5) Designation of the final disposal spaces

Two days after the earthquake, the authorities decided that incombustible wastes should be used for land reclamation at the Phoenix project and the remaining disposed in landfill dumps. The incombustible parts were mainly used for the project, however some recyclable materials such as concrete wastes were recycled and used as filling material for construction. This method can improve the efficiency of the usages of the resources. Final disposal spaces need to be decided quickly after the disaster. It is therefore suggested to be prepared to estimate the amount and the type of generated rubble, as well as tackling the administrative issues in advance to avoid legislative problems.

On the other hand, Problems related to traffic management and the transportation of rubble, are summarized as follows:

(1) Problems related to traffic management
There was difficulty in accurately assessing the damage.
Transport was not coordinated. There was no coordinating transport management.
The team was not responsible for the damage that worsened over time, becoming a hazard itself.
There was no plan to decide for emergency routes, evacuation places, and logistics nodes.
There was not enough public information for the citizens on the affected routes during the emergency, resulting in severe traffic congestion after the disaster.
Heavy machinery could not be operated due to street blockages.
There was no cooperation among different authorities, resulting in coordination difficulties for drivers operating across different regions.

(2) Problems related to transport routes for rubble disposal

- There was severe congestion at the access roads to disposal spaces and temporary stock yards due to the large number of vehicles involved in rubble disposal. Night time driving brought disturbances to residential neighborhoods.
- Parts of roads were inaccessible due to collapsed buildings; especially roads in the old town.
- Vehicles for rubble disposal caused traffic congestion to the affected area.
- The number of truck depots was too small (only three in the Kobe area) causing congestion and resulting in less efficient usage of delivery trucks.

From the above problems, the points of concern when deciding the logistics system for rubble disposal are:
- Preserve the connecting points between the temporary stock yards and vehicle waiting spaces.
- Utilize water transport as much as possible in order to reduce pollution and traffic congestion.
- Plan in advance and in details the emergency routes, the connection points, and the temporary stock yards.
- Prepare a logistics system to coordinate among municipalities in order to facilitate the operation of vehicles and machines used for rubble disposal purposes.

2.2 Rubble disposal plan for the Koto-ward of the Tokyo region

In the disaster prevention plan for the Koto-ward of the Tokyo region (Koto-Ward Disaster Prevention Division, 2008), the central municipal authority is designated as the center of management, and has responsibility for gathering data on the level of damage and provide support to each of the municipalities. The coordinated operation involves each municipality, which follow the management plan received from the center. At the same time, several organizations related to rubble disposal (including the Tokyo Bureau of Environmental Protection and the Tokyo Metropolitan Government Bureau of Port and Harbor, etc.) cooperate and assist the management center. The plan for rubble disposal is similarly to recycle wood and concrete rubble from collapsed buildings.

There are three types of temporary stock yards for different purposes and time periods. First, the primary temporary stock yards are designed to operate soon after the earthquake happens.
This space is assigned for storage of rubble removed from infrastructures, rubble blocking emergency roads, and rubble from the collapsed buildings as well as material classification. Secondary temporary stock yards are used from about 2 weeks after the earthquake. This type of stock yard is for storage of the rubble from collapsed buildings as well as rubble dismantling processes. Third, the tertiary stock yards for recycling works are planned to operate a month after the disaster. These stock yards are equipped with facilities for material classification, debris separation, and the other related works for a smoother operation of the recycling processes. Figure 2 shows the rubble disposal method in the disaster prevention plan of Koto-ward (which is one of the 23 wards of the city center in Tokyo).

![Figure 2 Diagram of the disposal method for Koto-ward](Source: Japan Environmental Sanitation Center, 2002)

3. TECHNOLOGIES AND TOOLS USEFUL FOR THE RECOVERY PLAN

(1) GIS

Three weeks after the 2004 Chuetsu earthquake (in Niigata prefecture), the Chuetsu Earthquake Restoration and Revival Support GIS Project was set (The Website of Chuetsu Earthquake Restoration and Revival Support Project, 2011). The project’s purpose was to provide information about the damage caused and the restoration process to the public. This
information was accessible through a webpage presenting a digital map using GIS technology. An example of the webpage is shown in Figure 3. The website is regularly updated and remains active today. The project is supported by both the public and private sectors. The information provided by the website includes traffic conditions and regulations and evacuation places (which were available until the end of 2005), restoration plans and information on volunteer support in each area. Restoration status is also provided with some pictures taken from the actual sites. Much of the work is done by volunteers who help to gather information from the websites of numerous authorities, assess progress by taking photographs, and update the information on the GIS system.

Figure 3 The display of website of the Chuetsu Earthquake Restoration and Revival Support GIS project.

(2) Traffic information system

Information about the damage on roads is generally very difficult to obtain after the earthquake. Principally, inspection tours are necessary to assess damages. Normally, this process is time consuming and considerably more time is required after large-scale disasters. Delays in gathering data on the level of damage cause more trouble to road users including emergency vehicles. Traffic information systems are therefore a useful tool to obtain damage information and support the operation of the actual inspection tours.

The technology of CCTV cameras that has rapidly developed in recent years can be very useful for traffic management as well as infrastructure management purposes. The CCTV cameras are used to monitor daily traffic activities in a normal situation and to investigate road condition and damage in the case of an emergency. During the disaster, the CCTV cameras are used to countercheck information received. It works together with the patrol car’s inspection tours in order to prevent further losses due to aftershocks. For the emergency usage, however, the operators of the system require a higher skill level than in a normal situation,
because large amounts of data need to be processed and time is of the essence. An efficient method to process large amounts of data from the cameras is essential.

The Ministry of Land, Infrastructure, and Transport (MLIT) generally provides live traffic reports, including information on: traffic incidents, congestion, and weather forecasts, through a traffic information system (The Website of MLIT, 2011). Large numbers of sensors and CCTV cameras are set up along roads throughout the country. This information is accessible via the internet for officials, road users, and other interested parties. The information is updated regularly, usually every 10-60 minutes. The system is also used for the purpose of disaster prevention. After earthquakes of more than 4 magnitudes on the Japanese scale, information on road conditions and traffic blockages will be collected; as well as the emergency inspections which are carried out. A decision, based on the inspection, will conclude whether or not the traffic flow in the affected region should be stopped, in order to limit further damage from aftershocks.

MLIT has set up the CCTV cameras system for an emergency case. The system is depicted in Figure 4. The cameras in standby mode change to the operation mode when an earthquake of more than 4 magnitudes on the Japanese scale attacks. The system then starts to record information into an automatically generated inspection sheet. After 24 hours have passed, if there no aftershock has occurred, the cameras’ status will return to standby mode. Otherwise, in the case of an aftershock of more than 4 magnitudes, a new inspection sheet will be again generated and the inspection process will be repeated. Since there are many numbers of CCTV cameras set up along the roadway, after the attack of large scale earthquake, among the possible destroyed cameras, there should be some still operating and can be used to gather the information.

![Figure 4 The operation of CCTV cameras’ inspection (Source: Nagata et al, 2007).](image)

(3) Insights from the usage of technology for the rubble disposal system

The Hanshin-Awaji earthquake caused huge damage, greatly disrupting traffic in many areas. It became difficult to operate the vehicles involved in rubble disposal. The situation was improved when the following steps were taken (Japan Dredging and Reclamation Engineering Association, 1996): (1) the vehicles for rubble disposal were given priority over other traffic thanks to the cooperation of the police, (2) large amounts of rubble was transported by
waterway, and (3) two traffic lanes of designated roads were preserved as emergency routes. Considering the lessons from the Hanshin-Awaji earthquake, it is suggested the Tokyo area to be prepared by:

- Estimating in advance of the amount of rubble generated by an earthquake.
- Specify the temporary stock yards: both primary and secondary stock yards, especially in urban areas with a high density of buildings.
- Decide the temporary stock yards for the work of material classification and further processes.

From the above list of requirements, the operation system of logistics rubble disposal is suggested by:

- The designated primary stock yards should be large enough for material classification to be carried out after dismantling. Secondary stock yards should be large enough to accommodate facilities for recycling processes.
- The combined usage of both road and waterway transport is suggested for a more efficient operation.

In addition, technologies such GIS as used by the Chuetsu Earthquake Restoration and Revival Project have received much attention from both the government and the private sector. Generally, the public sector is in charge of information on the road damage. On the other hand, some places or some information is gathered by the private sector and other interested parties in a variety of formats, including photographs from mobile phones. This is considered a chance to integrate the information from public, private sector, and individuals to improve quality of the information.

An emergency logistics system for food and rubble transport is critical. Based on experience from previous disasters, as well as logistics systems in normal times, the utilization of know-how from the private sector can significantly improve the efficiency of the operation. The proposed IT logistics system for rubble disposal is based on the following perspectives:

- Use the normal operating system for data gathering and other processes but with an enhanced capability for emergency situations to avoid confusion with the entire new system.
- For a disaster information center and its management, follow the example of the GIS project of the Chuetsu Earthquake Restoration and Revival Project.
- Set up a standard to process data from different formats.
- Change the slow analog data format to digital format to improve efficiency.

4. LOGISTICS SYSTEM FOR RUBBLE DISPOSAL

An efficient rubble disposal operation is most important for city restoration. The issue on how to quickly remove and dismantle the rubble was the most serious concern during the restoration after the Hanshin-Awaji Earthquake Disaster. Especially, the area located close to the stock yards and the truck depots experienced severe traffic congestion and pollution. Moreover, congestion became the biggest cause of delay to the operation as traffic jams in the area around the disposal space was up to 12 km in length. An adequate coordinating system is therefore necessary to ensure the smooth operation of the rubble disposal effort.

In the Tokyo metropolitan area, the potential amount of rubble that could be generated was
estimated to be as large as 100 million tons (Research Committee for Capital-Epicentral Earthquake, 2004). Therefore the rubble disposal system is a crucial issue in the urban restoration plan. Based on a survey of operations after the 2008 Iwate-Miyagi earthquake (Nihon Kikai Koyou and Engineering Advancement Association of Japan, 2010), it required 2 days to assess the level of damage and even longer to confirm the scope of damage. It is estimated a much longer time would be required for the case of large-scale earthquake, especially if it occurs in the Tokyo region.

Figure 5 depicts the flow of rubble disposal, envisaged by the management system, right after

![Image of rubble disposal management system](image-url)
the disaster until the restoration period begins. The information on operations and the positions of machines and dump trucks is collected through GPS as the GPS devices already be installed in trucks and working machines.

In an emergency situation, the location and condition of the machines can be acquired using the GPS technology and used together with the information on traffic and damage conditions from both public and private sectors for the management of truck and machine operations. At the same time, estimates of the amount of generated rubble can be updated with new data, using the GIS system. The system then reports the condition in the form of route guidance as well as information on the damage to roadways and dwellings. The collected information including air photographs is also transmitted to each of the parties assisting in the operation. Information on road damage is collected from several parties: officials, private sectors (eg. probe vehicles, delivery trucks, etc.) and individuals. The management plan should identify how to deal with information from different parties in a variety of formats.

After a month has passed, the situation turns to the restoration period. Work on the logistics operation for rubble disposal is started. Using information from the GPS including traffic and road conditions, the disposal logistics system and the management of stock yards can be operated smoothly with the traffic guidance system. This technology can help to avoid congestion at the access roads to the stockyards and increases the performance of the operation of the machines as they can avoid both damaged and congested roads.

5. A SCENARIO

5.1 Study area

The Koto delta area is selected as a case study. It covers the area of three wards located between two rivers (Arakawa River and Sumidagawa River) among Koto-ward, Sumida-ward, and Eidogawa-ward. This area is selected for this study because this area is predicted to be the most affected when an earthquake occurs. Figure 6 depicts the study area colored by level of danger that buildings in the area will collapse in an earthquake (Bureau of Urban Development Tokyo Metropolitan Government, 2008).

Figure 6 Study area
(Source: Bureau of Urban Development Tokyo Metropolitan Government, 2008)
Many buildings in this region are rather old and likely to collapse or burn down in an earthquake or its aftermath. Especially, this region has few public parks that act as buffers that prevent continuous burning of buildings from fire, or could serve as primary temporary stock yards for rubble disposal. These characteristics cause significant difficulties for rubble disposal in this region.

Based on the rubble disposal plan for the Koto-ward, the first and secondary temporary stock yards should be decided as well as a temporary depot for trucks. Parks located within the area are selected as the primary temporary stock yards as shown in Figure 7. The rubble generated in each circled area is planned to be moved to a nearby park depicted in each of the green squares in the figure. Trucks are assigned one of two operations: trucks operating between the affected areas and the primary temporary stock yards, and trucks for works between the primary temporary stock yards and the larger secondary temporary stock yards. As the area is located close to the river, rubble can be transported also by water along the river.


5.2 Simulation

This study has carried out a simulation of two cases. In the first case, rubble is transported directly by dump trucks to the secondary stock yard, in which it is expected to cause congestion and hence more pollution on the delivery routes. In the second case, the rubble is at first transported to the primary temporary stock yards by dump trucks and later the rubble is moved to ships along the canals to the secondary stock yards where possible. Table 1 lists the conditions when performing simulation of each case.

<table>
<thead>
<tr>
<th>Estimated Rubble</th>
<th>Case I</th>
<th>Case II</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 mill. ton from Sumida-Ward</td>
<td>2-ton and 4-ton trucks are used to transport rubble to the secondary stock yard.</td>
<td>All is transported by ship.</td>
</tr>
<tr>
<td>2 mill. ton from Koto-Ward</td>
<td>2-ton and 4-ton trucks are used to transport rubble to the secondary stock yard.</td>
<td>Some is transported by ship and the other by trucks.</td>
</tr>
</tbody>
</table>

The result is calculated based on the following criteria:

1. Travel time of one round trip from the affected area until the primary stock yard is the travel time during peak hours obtained from the survey of road traffic census.

2. In this case, Travel time = Travel distance / (Travel speed at peak hour + 20%) (Assuming that the travel speed is 20 percent slower than the peak hour speed at the normal condition)

3. A similar method is applied to calculate travel time between the primary stock yards and the secondary stock yards.

4. The required number of trucks by each type (small and large trucks) is calculated based on the estimated travel time.

The calculation results can be the amount of vehicles required for the rubble removal work within the shortest time period. In this study, the authors, however, focus more on another important aspect which is the environmental concern. The work should be finished fast as well as to produce less environmental effects. Therefore, the results are estimated in terms of vehicle hour traveled (VHT) and the exhausted gas and particles including NOX, SPM, CO, and SO2. The comparison between two cases is depicted in Table 2. Base case is calculated in the normal condition that there is no operation of the disposal trucks where Cases I and II are the operations by using truck only, and truck with water transport for removal of the total 4.5 million ton of estimated amount of rubble, respectively. The result shows that Case II with the combined usage of road and water transport produces less environmental pollution in all indicators. Based on the calculation results, the plan for operation is suggested to be done by dump trucks together with ships that used for transport of rubble along the canal. Waterway transport is more effective since it can transport more amount of rubble at each time comparing with trucks. Utilizing together all possible transport modes provides the most efficient way for the operation.
Table 2 Comparison results between two cases

<table>
<thead>
<tr>
<th>Description</th>
<th>Numbers</th>
<th>Comparison to the Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHT (veh-hrs)</td>
<td>Base 211,230</td>
<td>Cases I 219,260 I 1.00</td>
</tr>
<tr>
<td>NOX (kg)</td>
<td>Base 3,850</td>
<td>Cases I 4,813 I 1.00</td>
</tr>
<tr>
<td>SPM (kg)</td>
<td>Base 264</td>
<td>Cases I 328 I 1.00</td>
</tr>
<tr>
<td>CO (kg)</td>
<td>Base 5,258</td>
<td>Cases I 5,869 I 1.00</td>
</tr>
<tr>
<td>SO2 (kg)</td>
<td>Base 305</td>
<td>Cases I 370 I 1.00</td>
</tr>
</tbody>
</table>

6. CONCLUSION

This paper has presented general guidelines for management plans to cope with the rubble generated by large scale earthquakes. A specific management plan is proposed for the area of Koto-Delta, Tokyo. The plan includes an operation procedure, specifying locations for primary and secondary stock yards for the rubble disposal process. As the estimated amount of rubble to be generated in this area is very large, a proper management plan should be established to deal with the rubble in order to minimize disruption to local communities as well as to increase the efficiency of the operation. A simulation has been presented to estimate the required number of dump trucks and ships for the operation as well as the estimated environmental impacts caused by these transports. The impact has been calculated in terms of amounts of exhaust gas and particles.

This paper provides guidance on a plan to deal with the rubble; however, for its implementation, it is necessary to address other related issues, such as, legislative issues, cooperation among government agencies, technological aspects, and more details on the actual operation, following the guidelines of the proposed plan. Especially, the operation
issues such as number of truck required and truck scheduling are necessary to decide in practice. However, this kind of information in fact cannot be confirmed until the real situation since we cannot know the destroyed roads as well as available trucks after the earthquake attack. Some suggestions could be a large scale simulation when an earthquake attacks the region to predict the destroyed roads. In addition, the simulation method used in this study was a simple calculation for a rough estimation using static travel time estimation. It is recommended to improve the calculation using the better estimation techniques such as dynamic routing simulation. These issues remain for further study.

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