Multi-period Temporary Depot Location Problem in Flood Natural Disaster Response

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Abstract

Because the formation or reformation of emergency logistics is a complex undertaking, this study proposes a multi-period location-routing model in the immediate aftermath of a flood natural disaster. The model can decide the temporary depot locations and make vehicle routing plans in which the amount of each relief supplies to be transported can be optimally determined. The temporary depot considered in this problem is a facility different from a typical warehouse on the fact that temporary depots are not set up to provide storage, but are created instead to facilitate transferring relief supplies from one carrier type to another carrier type at the flood boundary. The most common transport means used in the real flood problem, trucks and boats, are considered in the model formulation. We begin by explaining the proposed mixed-integer programming model which employs a dynamic approach to locate the temporary depots, after which we conduct a set of numerical experiments to test the model formulation and analyze the characteristics of the optimization problem. The experimental results indicate that, based on flood disaster characteristics, our model is capable of showing the optimal locations of temporary depots in the flood response operations.

Keywords (12 font)
Emergency Logistics, Location-Routing Problem, Multi-period Model, Temporary Depot, Flood Natural Disaster.

1. Introduction

According to the International Disasters Database (EM-DAT, 2018), an average of 210 million people were affected yearly by weather-related disasters between 2007 and 2016. The frequency of geophysical disasters (earthquakes, tsunamis, volcanic eruptions, and mass movements) remained broadly constant throughout this period, but a sustained rise in climate-related events (mainly floods and storms) pushed total occurrences significantly higher. EM-DAT data contained in a 2017 report by the Centre for Research on the Epidemiology of Disasters (CRED) show that flooding caused the majority of disasters between 2007 and 2016, accounting for 41% of all recorded events and affecting nearly 85 million people each year. As recent events have proven, floods are the most common and most costly natural disasters. While it seems to be impossible to entirely prevent flood situations, steps can be taken to minimize injuries and losses and speed the recovery response process.

The formation or reformation of emergency logistics following large-scale and catastrophic disasters is a complex undertaking. In such situations, established and improvised agencies frequently work alongside government organization, to instantly deliver relief supplies and services. It is expected more specifically to rescue lives, minimize pain and suffering, and even give comfort. Emergency logistics in disaster relief are driven by different objectives and mechanisms than commercial logistics and supply chains. Moreover, plans work under specific conditions that would irritate most commercial logistics managers. The operating environments can be extremely uncertain and dynamic then the unique management methods must often be manipulated.

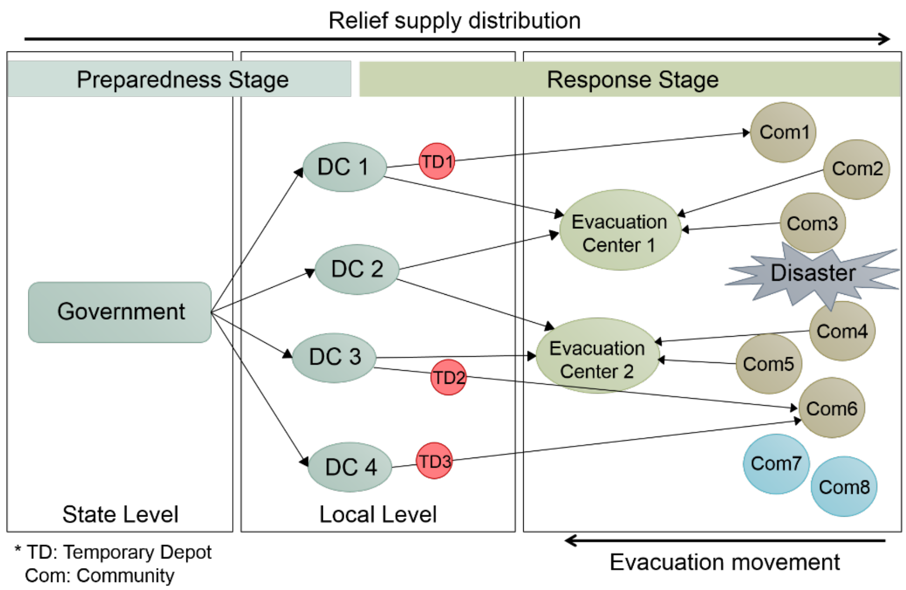

Figure 1. Supply chain management for flood disaster with temporary depots

Emergency management comprises two major phases, preparedness and response, which are applicable to pre- and post-disaster operations, respectively, as shown in Figure 1. The preparedness stage is a planning system put in place before disasters occur in order to make decisions on the location of related facilities and relief supplies. Schemes that are usually taken into consideration during this stage are stock prepositioning, the selection of distribution centers (DCs) and evacuation centers (ECs), as well as the evacuation planning. The response stage is the later process of relief distribution that commences immediately after a disaster occurs. The main thrust of the emergency response operations is related to rapid deployment of resources and aid within the first three days or 72 hours (Banomyong and Sopadang, 2012). In this response stage, vehicle transportation plans must be decided and capable to provide rapid movements. The quick response schedules are for delivering appropriate relief supplies from the DCs to the demand destinations including both ECs and affected communities.

Our former study (Manopiniwes and Irohara, 2017) developed a stochastic linear programming for integrated decision-making in strategic planning for the pre- and post-disaster operational stages where a flood was applied as the case study. Unlike other natural disasters, a massive flood often requires the decision on temporary depot locations over time apart from the first strategic decision on distribution center locations. For the remaining demand in flooded area, boats are needed for delivery because truck is no longer applicable for land transportation due to the obstacle by water. For this reason, the temporary depots must be taken into the consideration in the relief logistics supply chain where the flood boundary will be considered as the candidate location for. These depots are not mainly for the storage function but for transferring the relief supplies from one carrier type to another carrier type. In this study, we extended the contribution by developing this former work to a multi-period approach that describes the the details of facilities location-routing in response to the immediate aftermath of a flood natural disaster.

2. Literature Review

The literature on strategic planning for logistics problems in disaster relief is rather rare but increasingly investigated in operations research (OR) society. The studies generally consider in different components of problems such as the location of emergency services, dispatching multiple commodities, uncertainty in supply and demand or traveling costs, etc. This section includes several models from a review article of relief supply chain optimization problems by Manopiniwes and Irohara (2014) and Boonmee et al. (2017). More recent articles have also been investigated.

One of the first studies on relief transportation plans, conducted by Knott (1987), considered the last-mile delivery of food items from a DC to a number of camps, while assuming a single mode of transportation and making direct deliveries to those camps. A linear programming model was developed to determine the number of trips to each camp needed to satisfy demand while minimizing the transportation costs or maximizing the amount of food delivered. Barbarosoğlu et al. (2002) focused on tactical and operational scheduling of helicopter activities in a disaster relief operation. They decomposed the problem hierarchically into two sub-problems where tactical decisions are made at the upper level, and the operational routing and loading decisions are made at the lower level. They also formulated mixed integer programming models for tactical and operational problems, which were solved by an iterative coordination heuristic. Balcik et al. (2008) and Vitoriano et al. (2009) focused on planning logistics at an operational level in a vehicle-based last-mile distribution system. Their models can be used to determine delivery schedules for vehicles, and equitably allocate resources, based on supply and vehicle capacity. Lin et al. (2011) proposed a logistics model for the delivery of prioritized items during logistics operations applicable to a disaster relief effort, in which they considered the delivery priorities of different items, and encompassed this idea as an objective function. Ransikarbum and Mason (2014) presented a multiple-objective programming model for the response and recovery phase in post-disaster operations. Their network optimization model was developed for making strategic decisions in supply distribution and network restoration during humanitarian logistics operations. Abounacer et al. (2014) presented a multi-objective location-transportation problem for disaster response that aimed at determining the number, position, and mission of required humanitarian aid distribution centers within the disaster region. Liberatore et al. (2014) introduced a model that combines recovery operations of transportation infrastructure elements with aid distribution planning in humanitarian logistics. Another recent paper by Salman and Yücel (2015) proposed selecting an emergency facility location to maximize the expected demand coverage within a specified distance over all possible network realizations. Even more recently, a two- stage scenario-based possibilistic-stochastic programming approach aimed at coping with the uncertainties and multiple objectives of decision-making problems simultaneously was proposed by Tofighi et al. (2016). In this work, uncertainties were treated by taking into account the inherent fuzziness and randomness in the available data. The model deals with preparedness and response planning, and also takes into account distribution planning of relief items during stock prepositioning. Sung and Lee (2016) modeled an ambulance routing problem that determines the order and destination hospitals for patient evacuations. Their model determines victim transportation priorities in mass casualty incidents (MCI) by explicitly taking into account the details of ambulance operations. Recently, Safaei et al. (2018) designed design an integrated framework for relief logistics operations by introducing a novel bi-objective bi-level optimization model. Goal programming approach is employed for the exact solution of the model to minimize deviations from the goals of the bi-objective problem. Rezaei-Malek et al. (2018) applied the real problem of floods in Acapulco, Mexico with their optimization model to determine the location of emergency facilities, stock prepositioning, resource allocation, and relief distribution.

However, while it can be seen that the study of emergency logistics has attracted significant attention in recent years, the number of studies that consider multi-period problems is limited. Özdamar et al. (2004) developed linear and integer multi-period multi-commodity network flows to coordinate logistics support for relief operations in which the model outputs consisted of dispatch orders for vehicles waiting at different locations in the area. Afshar and Haghani (2012) developed a mathematical model that describes the integrated logistics operations in response to natural disasters. The structure of the network was in compliance with the complex logistics structure of the US Federal Emergency Management Agency (FEMA). The objective of this model was to minimize the total unsatisfied demand for disaster victims. The model itself was formulated as the weighted total of unsatisfied demand summed over all victims, for all relief items, and during all time periods. To the best of our knowledge, a multi-period approach has not yet been dealt with the temporary depot problem regarding to floods disaster. The selection of temporary depots for supplies transfer between different carrier types has never been found to treat in this area when considering time horizon in the area of emergency logistics. A unique and special of flood character is about the dynamic capabilities. Floods may not hit as urgently as earthquake or other natural disasters but present the unstable size and impact over time instead. In particular, the most common transport means in the case of flooding are trucks and boats in unaffected areas and flood areas respectively.

3. Problem Definition and Model Formulation

This section presents a problem definition of the temporary depot location as it pertains to flood disasters as well as the model formulation.

3.1 Problem Definition

While there are a plenty of studies related to the decision making model on preparedness and initial response stages, in this current study, we propose the framework for a new perspective problem on temporary depot location regarding to floods disaster. The temporary depots location problem is aimed at determining the optimum resource allocation among affected people in flood disasters in order to minimize logistic operation costs while maximizing support to the affected people. More specifically, the temporary depots location problem determines (1) location of temporary depots, (2) delivery transportation plans, (3) vehicle routes, and (4) the amount of relief supplies delivered from temporary depots to demand points in floods area. The difference between the temporary depots location problem and permanent facilities location problems is on the fact that these depots are not mainly for the storage function but for transferring the relief supplies from one carrier type to another carrier type where the flood boundary will be considered as the candidate location for.

In flood disaster response at an operational stage, we focus on the distribution management of relief supplies to a number of demand points in its flooded districts. Once a flood happens, the government or aid agency send a group of skilled people to the flood areas to evaluate the type and amount of relief supplies needed. With this information, the aid agency begins to locate the temporary depots in the candidate locations which are completely as the boundary of floods. Since the aid recipients or demand in floods disaster can be divided into two categories as evacuee in evacuation centers and remaining people in affected area. Unlike other natural disasters, a massive flood often requires the decision on temporary depot locations over time besides the distribution centers. Those temporary depots are not mainly for the storage function but for transferring the relief supplies from one carrier type to another carrier type. For the remaining demand in flooded area, boats are needed for delivery because truck is no longer applicable as the land transportation due to the obstacle by water as shown in Figure 2. Therefore, the need of location plan for temporary is crucial in this problem description.

Figure 2. Flow of relief supplies in flood disasters

3.2 Model Formulation

A multi-period mixed-integer programming model is presented in this section focusing on the response stage of a disaster management principle.

The index sets employed in the formulation of the temporary depot problem are the sets of points in the network $i, j \in N$ where DC is a set of permanent distribution centers, TD is a set of temporary depots, and DP is a set of demand points. $m \in M$ is a set of transportation means where A is a set of truck and B is a set of boat. The time horizon of operations is denoted $t \in T$ in the formulation.

The binary decision variable Z_{it} is 1, if temporary depot i is selected to be operating on point i at time t, 0 otherwise. Y_{ijt}^{m} is a binary decision variable 1, if the vehicle m travel from point i point j at time t, 0 otherwise. The decision variable X_{ijt}^{m} represents the amount of relief supplies shipped from point i to point j at time t by mean m while the decision variable U_{it} is the amount of unmet demand in point i at time t.

The parameters in the formulation are the demand point i at time D_{it}, the capacity of each facility both permanent distribution centers and temporary depot Cap_i, the maximum number of temporary depots at time t E_t

The objective function of the problem formulation is given as $\sum_t \sum_i U_{it}$ to be minimized the total amount of unmet demand for over all the periods and demand points which is subject to the several constrains as follows

- The constrain of transfer points requires that, for transfer point at each temporary depot, sum of relief supplies coming to each point minus sum of relief supplies leaving the same point is smaller or equal to the capacity of each temporary depot.
- The constrain of demand points shows that the total relief supplies coming to each demand point plus the unmet demand is equal to the unmet demand at that point, including any unmet demand from the previous period.
- The constrain of facility capacity enforces the total capacity of temporary depot in the system each time period cannot exceed the maximum number of temporary depots.
- An uncapacitated vehicle routing is considered based on the assumption that we have plenty of carriers during the flood response.

4. Computational Results

To evaluate a proposed model formulation, a set of numerical experiments are conducted to analyze the features. We generate the data sets in a small sample size, so that it can be solved by commercial solver. The small size problem however still represents all the elements of the model formulation. The locations of candidate temporary depots and demand nodes are randomly generated in a uniform distribution on a 4000*4000 square

We demonstrate illustrative examples that present how the model formulation can be used to optimize the locations of temporary depots for each time period. As it is certainly agreed that the first three days or 72 hours is critically important for the response stage of disaster relief management principle. Therefore, example results in this research refer to the solution according to this information as the first 72 hours delivery plan right after the city has been attacked by floods.

Considering time scale is crucial that can forcefully impact the time-scale networks performance. The problem size may increase hugely with shorter time steps due to the number of time scales in the planning horizon while the problem tends to stay at a reasonable size in longer time scales (Afshar and Haghani, 2012). In this study, hours is appropriate than minutes according to those activities needed in floods response stage. Both delivery flow and transfer nodes requires at least couple hours but less than six hours to complete. Thus, each six hours is appropriate for treating in this problem.

At the beginning of $t = 6$ hours, we can see that two temporary depots are located and providing the delivery to the nearest several demand locations by their capacities. These two locations are selected for locating the depots at the beginning because it can serve large size demand shortest among other candidate temporary depot locations. Next at $t = 12$ hours, two temporary depots are remaining the same locations to serve the same medium and large size demand and the other nearest demand points. The first two small size demands are completely satisfied in the last period and aleady presented in black colour node. The same locations of temporary depots are displayed until the end of the first day at $t = 24$ hours. One of depots in the lower relocates to the new locations in order to serve new more nearest demands. The same situation happens in the upper temporary depot that moves in $t = 36$ hours. Finally, the lower temporary depot has stopped to operate in $t = 66$ hours since only one depot is enough to provide the service to the remaining demand until complete the satisfaction in the last period at $t = 72$ hours.

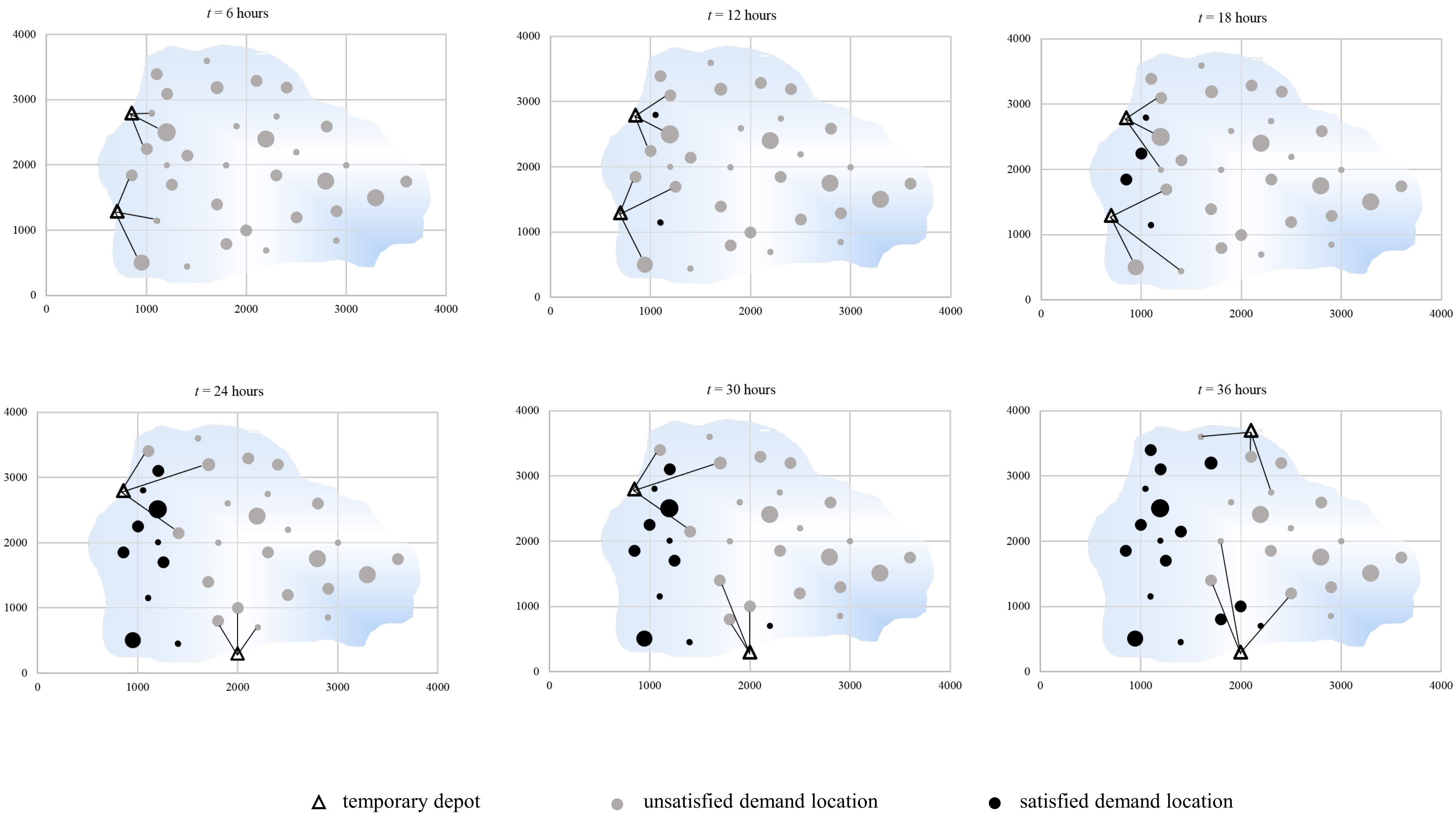

Figure 3. Location results of temporary depots at each time period

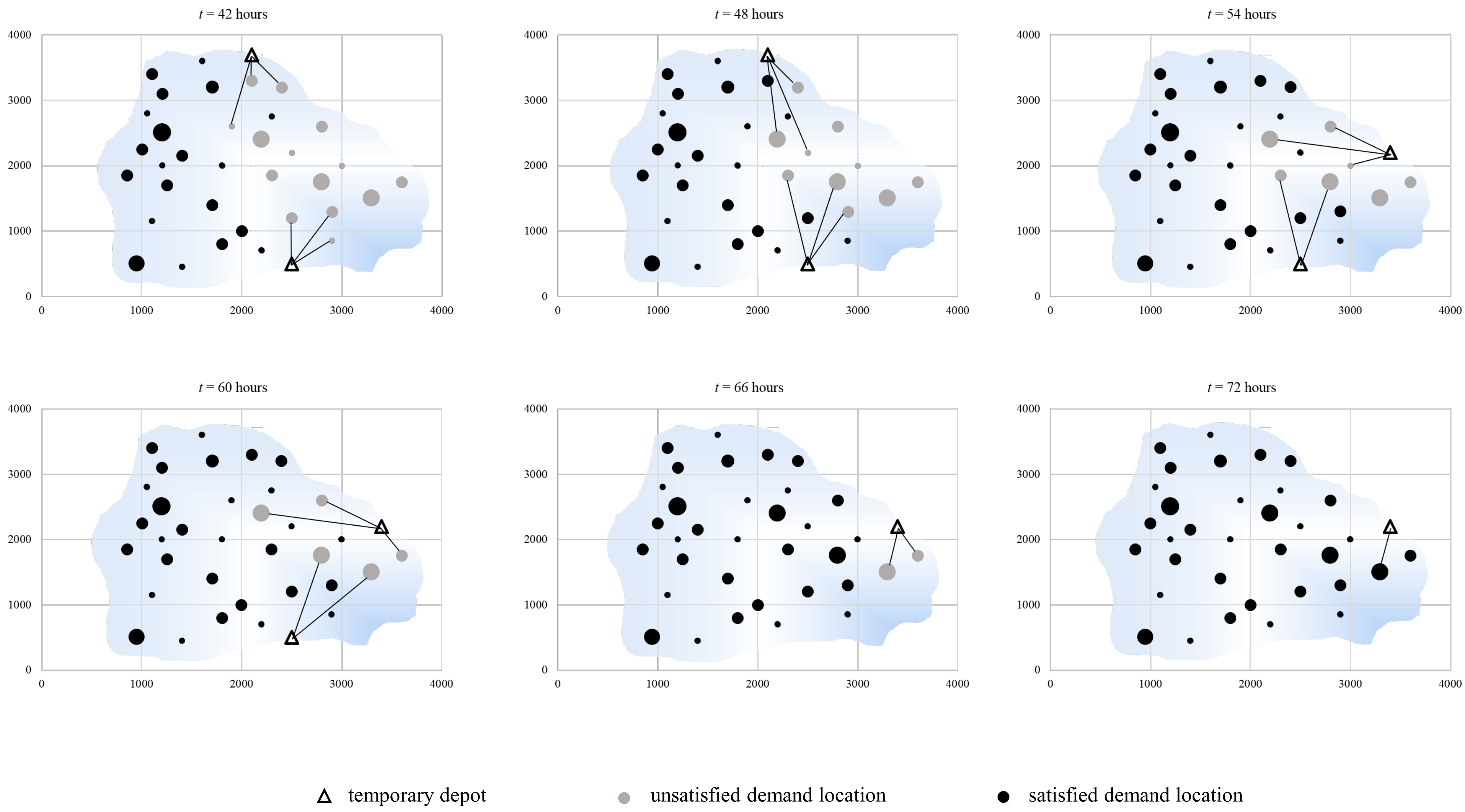

Figure 3. Location results of temporary depots at each time period

5. Conclusions

The study extended the contribution focusing on the operational level in the immediate aftermath of a flood natural disaster. The location-routing model is proposed to the particular temporary depot problem regards to a multi-period approach. The model can decide the temporary depot locations and make vehicle routing plans in which the amount of each relief supplies to be transported can be optimally determined. The temporary depot considered in this problem is a facility different from a typical warehouse on the fact that temporary depots are not set up to provide storage, but are created instead to facilitate transferring relief supplies from one carrier type to another carrier type at the flood boundary. The most common transport means used in the real flood problem, trucks and boats, are considered in the model formulation.

We demonstrate illustrative examples that present how the model formulation can be used to optimize the locations of temporary depots by the first three days of emergency response. More number of resources are able to provide better response that can complete the satisfaction faster than the small number of available resources. The proposed model shows the optimal locations of temporary depots for each time period regarding to demand in floods. The approach is referred as a valuable tool for the decision maker that suggest the plan for locating and relocating temporary facilities for each time period in order to provide the optimal response delivery.

Though, there are a number of research expansion of this study, future research will seek for more complex and larger problems. The application of a heuristic algorithm is prospected to offer opportunities for better improvement when sizes and complexity of problem become greater. This can be expected to help finding proper and satisfactory solutions to problem processes.

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