Effect of En-route Reassignment of Hospitals for Ambulances

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***Abstract*—This paper proposes a hospital assignment scheme for ambulances transporting patients, aiming at efficiently re-matching both parties even in the case of a demand surge. Built on top of the minimum cost maximum flow model, the allocation process adjusts link connectivity in the flow graph according to whether a patient can be cured at a hospital, reach within a deadline, and be reallocated to another hospital even while on the move. The prototype implementation using the Java language shows that the proposed scheme can reallocate patients with stable reassignment overhead, with the total moving distance being managed below 4.3 %.**

Keywords—emergency rescue, hospital assign, maximum cost minimum flow, en-route re-matching, relocation overhead

I. Introduction

Smart cities are providing diverse smart services benefiting from prevalent communication technologies [1]. EMS (Emergency Medical Service) is one of the most important applications in our city lives and the connectivity between patients, ambulances, call centers, and hospitals makes it possible to save more lives [2]. On the arrival of an emergency request, the call center dispatches an ambulance to the spot, paramedics give treatment, and the ambulance transports the patient to a hospital. In this process, each entity communicates with appropriate communication channels and accurate information must be available regarding real-time traffic conditions, current location and equipment of ambulances, symptoms and past medical history of patients, availability of hospitals, and the like [3].

In the meantime, there can be an emergency request surge during a short time interval [4]. Then, the ambulance-to-patient matching or patient-to-hospital matching must be integrated, rather than sequentially assigning a target object. Our previous research has designed an ambulance dispatch scheme that matches ambulances and patients, considering the current location of ambulances and the criticality of patients [4]. On the contrary, this paper is to design a hospital assignment scheme for patients who have been treated by paramedics on-site and must be transported to a hospital to get complete treatment. Both schemes are quite symmetric, in that bipartite matching is essential between two parties. Moreover, it is also possible that new patients can request emergency rescues while ambulances are on their way to pre-assigned patients or hospitals.

However, even after a hospital is assigned to a patient and an ambulance is on its way to the assigned hospital, the destination can be changed en route when patients in a more critical condition are to be charged to the target hospital. The criticality is quite accurately determined by the paramedics and reported to the call center [5]. The reallocation process must select those patients who can be reallocated considering their severity, namely, whether they can afford to accept the prolonged driving time. To this end, it is necessary to minimize the number of reassigned patients, while reducing the total moving distance of the ambulance fleet. In this regard, this paper is to challenge the hospital reassignment problem for patients in ambulances and measure the overhead inevitably induced by reallocation.

II. Design of a Dispatch Mechanism

For patient-hospital matching, the MCMF (Minimum Cost Maximum Flow) scheme can minimize the cost defined by a series of criteria, such as total driving distance or time, responsiveness to critical patients, and the like [6]. It is necessary to build a flow graph from a virtual source to a virtual sink. Here, each patient (ambulance) and hospital forms a node. Specifically, if a hospital can accommodate multiple, say n, patients, the hospital adds n nodes to the flow graph as shown in Figure 1(a). A link can be connected between a patient node and a hospital node when the patient can reach within a certain bound and the hospital can give appropriate treatment with the necessary medical staff and equipment.

After this bipartite matching is accomplished, it is possible that a new set of patients additionally want to be charged to hospitals. In this case, it is necessary to build a new flow graph. The new patients add more patient nodes as shown in Figure 1(b). The reallocation process first identifies the changeable patient nodes by the criticality of patients and the remaining distance to drive. If the remaining distance is short, the reassignment will bring much overhead, as the transportation taken up to the instance will be highly likely wasted. If an assignment is unchangeable, the link weight from the source to the patient node and that from the hospital node to the sink are set to 0. Then, another execution of the MCMF solver creates a new assignment. If an additional set of patients requests takes place, the same procedure will be triggered.

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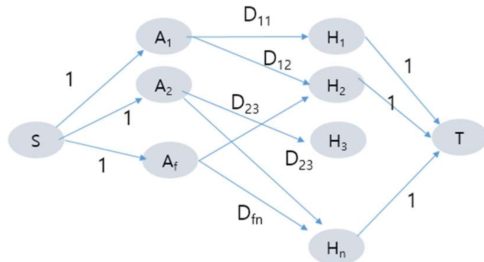
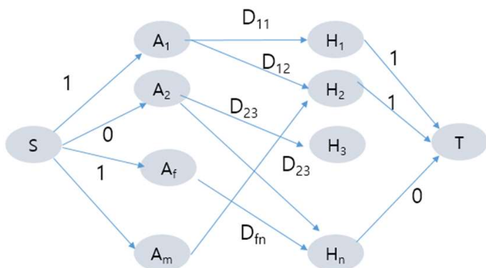


(a) 1st stage flow



(b) 2nd stage flow

Figure 1 Flow graph establishment

III. PERFORMANCE MEASUREMENT

We implement a prototype version of the proposed scheme with the Java language and measure the performance mainly in terms of the total driving distances taken by whole emergency vehicles to reach respectively matched patients. Moreover, the experiment takes one more performance metric, namely, the number of reassigned patients, as we are interested in the reallocation behavior. In the experiment, the number of patients or the number of ambulances to be assigned to hospitals in the first stage is set to 50, while the number of total hospitals is set to 100. The distance between a patient and a hospital is assumed to be given in advance. Here, the distance can be replaced by the driving time, so distance and driving time can be used interchangeably, and its unit doesn't have to be explicitly specified. In addition, performance parameters include the time interval between two allocation processes, the number of requests added in the second stage, and the ratio of non-changeable assignments in the previous stage. The default values of these three parameters are 3 units, 10 requests, and 0.3, respectively.

The first experiment changes the length of the time interval between two allocation processes from 0 to 10, while other parameters are set to default. In the first stage, 50 requests are assumed and after the interval, the second stage assigns hospitals with 10 more patients. Those patients who cannot be changed and almost reach their destinations are excluded in the second stage allocation with the adaptation of the flow graph described in the previous section. If we know all patient requests before the allocation process, the MCMF scheme can minimize the cost. The experiment compares the reallocation overhead with this ideal case. Figure 2 plots the moving distance according to the time interval between the two executions of patient-to-hospital matching. For a larger interval, reallocation rarely takes place, and even if a subset of hospitals are already assigned, the allocation scheme finds appropriate hospitals. For the case of intervals up to 4, changed routes add total driving distance. However, the driving distance after the second allocation will be shortened.

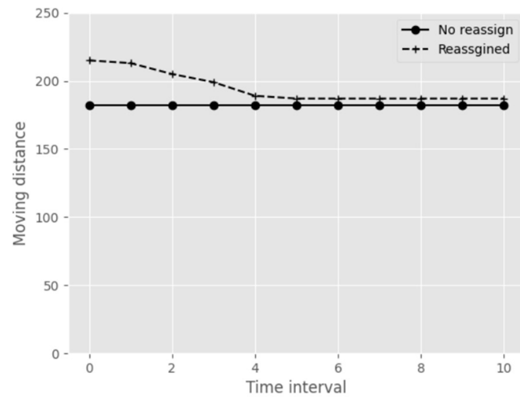


Figure 2 Total moving distance vs. time interval

Next, Figure 3 plots the number of reallocated patients according to the time interval. For the time interval of fewer than 3 units, more than 8 out of 50 patients change hospitals while driving. However, time interval gets larger than 5 units, two allocations are independent. The only condition we can further take into account will be the ambulances having completed the previous transportation and reaching other patients during this interval. In that case, the set of patient nodes must be adjusted.

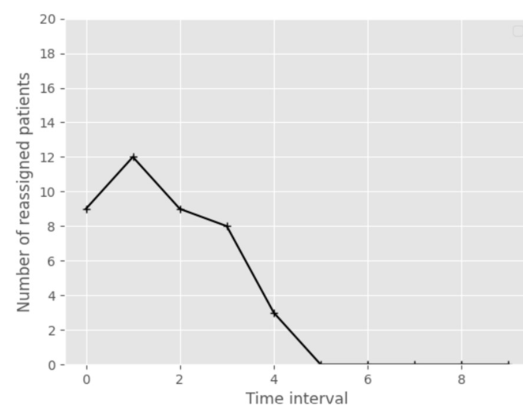


Figure 3 The number of reassignments vs. time interval

The next experiment changes the number of patients who should be additionally allocated to hospitals in the second stage. Figure 4 shows that the moving distance increases linearly according to the increase in the number of added patients, indicating that the relocation process works quite stably. The gap between the two curves is almost unchanged, and the distribution of hospitals will be more important.

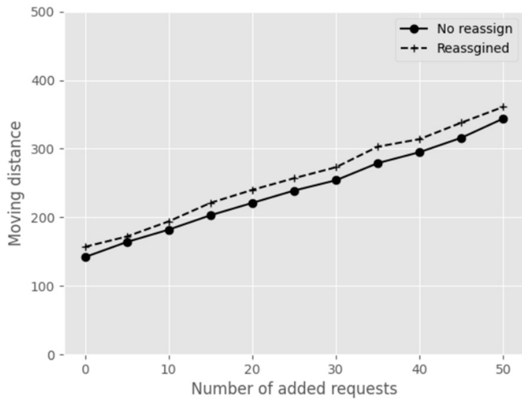


Figure 4 Moving distance vs. number of added requests

Figure 5 measures the number of reassigned patients according to the number of added requests. Even though the number of reallocated patients increases with the increase in the number of requests in the second stage, both factors are not so correlated.

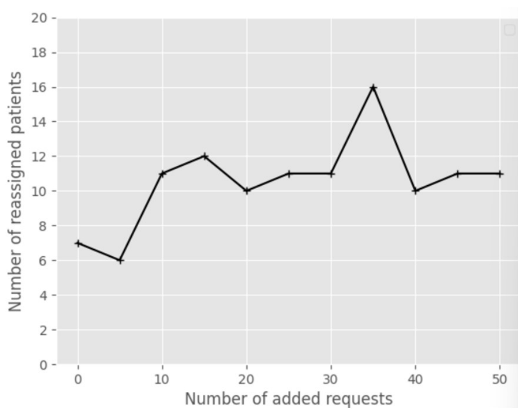


Figure 5 Relocated patients vs. number of added requests

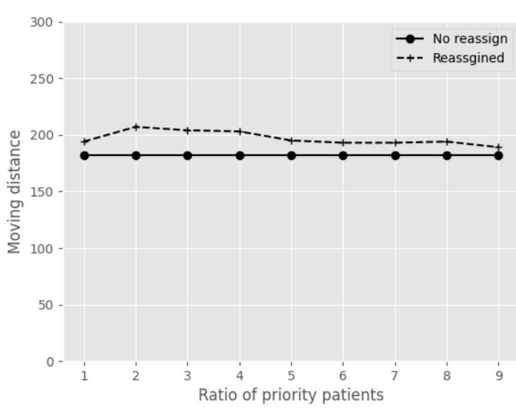


Figure 6 Moving distance vs. ratio of priority patients

The next experiment measures the effect of the ratio of priority patients who should not be reallocated during the second allocation process as they are in critical situations. Figure 6 shows that the moving distance will increase when fewer patients have priority and more patients can be reallocated.

Figure 7 plots the number of reassigned patients for the range of priority patient ratio from 1 to 9. Interestingly, when 30 % of patients are not to be reallocated, the number of reassigned patients gets higher. Our analysis finds that even if patient nodes participate in the second stage allocation, their hospitals are rarely altered.

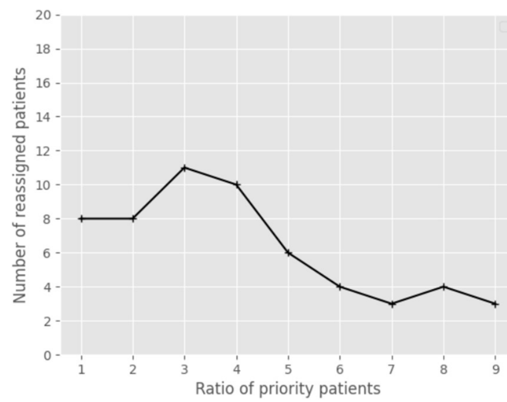


Figure 7 Relocated patients vs. ratio of priority patients

IV. CONCLUSIONS

This paper has proposed an incremental ambulance-hospital matching scheme in the case of a demand surge. The multi-stage MCMF with the adjustment of the flow graph can reduce the driving distance and response time with stable overhead for the given parameter setting. The efficiency of MCMF makes it possible to repeatedly execute the allocation procedure. In future work, we are planning to interwork with the hospital information standard such as FHIR (Fast Healthcare Interoperable Resources) [3] for a more comprehensible data orchestration.

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