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Research Article

Multiobjective Based Resource Allocation and Scheduling for Postdisaster Management Using IoT

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Disaster is an uncertain phenomenon that arises due to natural as well as man-made calamities. Disaster often causes a high degree of destruction, especially in a very densely populated region. To handle such a situation, efficient resource management strategies are required. Resource management is the most crucial phase of disaster management. Efficient and in-time allocation of resources is very important; otherwise, it may result in more fatalities. In this context, we propose the resource management algorithm, which deals with both over- and underdemand for resources. Resource management requires efficient resource allocation, and in case of overdemand for resources, it must be followed by resource scheduling. In this paper, we introduce a resource allocation technique which is based on multiple objectives having a different set of constraints. We also propose the resource scheduling algorithm based on various parameters. The proposed algorithm uses multiobjective theory for resource allocation which is followed by the implementation of priority-based scheduling technique, in the case of overdemand for resources. Our proposed methods are compared to the existing approaches in the literature. From the simulation results, it is clear that our methods perform optimum resource allocation and scheduling operations.

1. Introduction

The disasters may be natural calamities or man-made hazards, which results in a huge loss of human lives and infrastructures [1, 2]. Disasters are unpredictable and suddenly occurring events which cause mass destruction. Disasters can be classified into natural disasters, such as earthquake, cyclone, flood, and tsunami, and man-made disasters, such as a nuclear explosion, oil spills, and gas leakage. If emergency situations are raised due to disasters, the rescue and recovery operations must be carried out efficiently and quickly. The rescue and recovery operations need different kinds of resources for performing various tasks. Thus, there is a need for optimal allocation of resources at multiple emergency locations. This is a challenging issue when there are multiple locations of disaster, and at each location, the set of rescue related tasks are needed to be carried out. During the last two decades, a lot of preventive and protective actions have been taken by the respective government to identify the disaster prone areas and prepare immediate action plans for postdisaster situations. However, the disaster is still considered as an unpredictable catastrophe. In this regard, it is very crucial to take quick actions to reduce the number of fatalities and minimize the destruction of infrastructure. There are two phases of disaster management [3–5]: predisaster phase and postdisaster phase, as shown in Figure 1. The predisaster phase deals with mitigation and preparedness. On the other hand, the postdisaster phase deals with the in-time response and quick recovery. Resource management is a part of postdisaster management. The effective prevention and mitigation strategies minimize the risk of hazard and its consequences by taking proactive steps.

Mitigation [7] requires long-term planning and learning from the experiences of earlier disasters. It includes public education, hazard assessment, infrastructure improvement, risk assessment, protection of critical infrastructures, and many more, while preparedness deals with volunteer management, strategy deployment, assessment management, and emergency detection, on a broader level. Disaster response activities include emergency shelter, search and rescue

Figure 1: Phases of a disaster management.

operations, treatment of injured people, damage assessment recovery, resource allocation, situation management, and stabilization. To perform the above-mentioned operations, the rescue team must have the knowledge of demands at disaster places, for which there is a need for coordination and cooperation among various tasks, such as search and rescue, setting up relief camp, and providing initial treatment to injured people. Search and rescue operations may include looking for missing people, providing first-aid, taking severely injured persons to the hospital, and providing them shelter to safe places. These operations are the most crucial and hold the highest priority. In this phase, an emergency warning is given to the common people using various means like media, social networks, and social platforms. Inventory management and vehicle tracking ensure efficient and faster ways for resource allocation. The recovery operation can be elaborated by reconstruction and restoration of services like electricity, communication, transportation, rehabilitation of ecosystem, and redevelopment, as and when required.

In the postdisaster phase, the most crucial task is to collect accurate information from disaster-affected regions. This may be performed by using an aerial surveillance system to collect the relevant data. The use of an aerial system is to obtain information about the ground situation like road network of the disastrous area. In such a situation, the unmanned aerial vehicle is considered to be a very useful and flexible tool for acquiring information about the ground reality. These data may be collected through appropriate sensors and devices, which may be deployed at the disaster sites prior to the disaster occurrence, as a part of mitigation through the aerial system. In the current scenario, the advent of Internet of Things (IoT) has made it possible to collect and communicate the acquired data using Internet and performing various tasks. One of the most important tasks in such situations is resource management. Resource management includes two important tasks, namely, resource allocation and resource scheduling. For instance, in case of an earthquake, several zones in a city may be affected. Over there, resources such as a crane, hydraulic jack, hydraulic cutter, an ambulance, first-aid support, food packets, and clothes are needed. Based on the kind of activities or tasks, various resources are distributed. An optimum resource allocation strategy decides how resources may be distributed from different warehouses to the affected region in time. However, in case of a limited number of resources, the resources must be scheduled to reduce the demand and supply gap during the recovery and rescue operations in the disaster-affected regions.

Resource management requires different objectives to be fulfilled depending upon the set of tasks to be performed. These objectives include various parameters like the cost of operation, technology to support real-time response strategies, satisfying demand in minimum time, and maximizing the utilization of available resources. In addition, there is a need to serve maximum possible affected areas with the available number of resources. This becomes even more challenging when all these objectives are needed to be fulfilled at all the places and at the same time. In such situations, resource scheduling and allocation play a vital role. The resource allocation strategy should allocate the appropriate number of resources at different places as per the demand in such a way that other places may be served with the remaining number of resources optimally. Also, resource scheduling supports the process of resource allocation by aiding efficient scheduling of the resources for the optimal allocation.

The allocation and scheduling operations need effective data collection and communication. If resources are tagged with appropriate sensor devices and RFID, then it becomes easy to avail the real-time information about various resources through an established network and it allows one to perform optimal allocation and scheduling of the resources. Thus, it is very important to set up such a network among sensor devices and it is expected that the network should be wireless and IP-enabled. Due to this, the data or information about the resources can be available from anywhere. This is possible with the help of an Internet of Things (IoT). The IoT helps in achieving the same purpose and it is possible to maintain the real-time record of the resources and disseminate this information where and when required. Internet of Things [8] is a modern emerging technology. It allows communication among things or objects from anywhere and at any time. Wireless Sensor Network (WSN) has limitations like energy constraint, limited communication range, low transmission, and reception power. IoT is an IP-enabled solution.

As part of predisaster activities, the mitigation and preparedness are very important, whereas for postdisaster activities, distributing resources in an efficient way in real time is very important. The distribution of resources must be done carefully and it is required to trace out whether the resources are allotted and utilized efficiently or not. In this process, mitigation or preplanning activities take care of the tagging of resources in advance. Even the suppliers nowadays are using bar code based resource identification with a detail of batch, date, and packaging information. So it is assumed that the resources are tagged with all details in the form of a simple barcode or with RFID tag [9]. While shifting these resources from the warehouse there is no need for manual efforts to maintain the stock of it. The tag reader may help

in this task. The concept of tagging is not only for nonliving objects or materials available for distribution but it may be for human resources having RFID enabled identity card with their skills and other details embedded on it. This information may be traced for utilizing the human resources efficiently. Even without RFID based tagging, some mechanism is required to trace the distribution of different resources. In this context, RFID based tagging helps in monitoring and tracking the resources. Also, in a logistic vehicle, a GPS module is attached on an IoT device. IoT device can be a low-cost standard device available with embedded boards like Raspberry Pi, Arduino, or Intel Galileo. In our proposed system, for demonstration and evaluation purpose, the IoT devices, Raspberry Pi, Arduino, and various sensor motes are used. A few of these motes are embedded with GPS modules as well. GPS sends real-time latitude and longitude to make it possible to track the resources tagged with such devices. Further, the system is also integrated with Google Maps, which shows real-time traffic scenario and road surfaces, which helps in real-time decision making.

This paper proposes a solution for real-time resource allocation and scheduling to handle the multiple objectives in case of postdisaster situations. The proposal first allocates the resources and schedule them to fulfill the demand for completing various tasks or activities at different locations simultaneously. The proposal uses four different aspects: priority of the task, transportation cost, resource utilization index, and scheduling time index, which are discussed later in detail in the proposed algorithm section. All these factors are combined in the proposal using a multiobjective based model for resource management. The optimization is performed using Lingo programming tool [10] and the real-time data and information are mapped using Android-based visual system. The outline of the paper is as follows: related work is described in Section 2. Multiobjective based resource management scheme for allocating and scheduling is proposed in Section 3. In Section 4, results and analysis are described and discussed. This is followed by a conclusion.

2. Related Work

In this section, a review related to resource management is presented. For postdisaster management, it is very crucial to handle resource allocation and its scheduling efficiently and in an optimized way. Managing resources is very difficult in case of various critical situations such as calamities and wars because one has to consider various parameters for decision making so as to reduce the fatalities. For example, in the case of postdisaster management for carrying out rescue and recovery operations, various parameters like distance from resource center, availability of resources, and number of people affected must be considered while allocating resources.

Conventional resource management systems used for postdisaster management are based on Geographical Information System (GIS), which uses geospatial data [11, 12] collected using various satellites. The GIS system compares the postdisaster geospatial data with that of a predisaster situation for assessment of damage occurred in the affected area. The GIS-based system works with the help of satellites. It is mandatory to hire satellite service for the GIS-based system which is expensive. Disaster management approaches using drones have been proposed in [13, 14]. The drone-based system helps in acquiring images of disaster-affected areas, but it does not provide location information along with it, which is generally available using the GIS-based system. To overcome this problem, nowadays drones are available with in-built GPS sensors so that the location information can be made available. Decision support system framework [15] has been proposed for decision making during disaster based on information collected from multiple agencies, previous disaster statistics, and records which were stored in a centralized system. The centralized decision support system [15] has been used for resource dispatching and tracking based on multiple criteria for disaster management. Here, multiple objectives are considered to allocate resources during an emergency situation to all the places that are severely affected by a disaster. Decentralized [16] resource management scheme for postdisaster allows periodic sharing of resource information by each relief camp in the delay tolerant network.

Resource management requires optimal resource allocation during the critical time and it is quite challenging. Resource allocation is the process of distributing the available resources in such a way that the maximum utilization of resources can be achieved. Resource allocation should ensure that each objective must be fulfilled in an optimized way by incorporating multiple constraints and criteria. A significant amount of research has been carried out in the fields of resource allocation for applications like healthcare management [17–20], logistic industries, manufacturing companies, cloud computing [21–23], and supply chain management [24]. Proper utilization of resources based on demand and availability is very important, in the absence of which, underutilization of resources has an adverse effect in terms of achieving the goals for an organization. These resources may include, but not limited to, the medical kits, ambulance, fire vehicles, food packages, and rescue boats. The delivery of these resources in real time definitely reduces the losses. Mohammed Muaafa et al. [25] have used multiobjective resource allocation scheme for a medical emergency response. This scheme considers a number of objectives like the location of an emergency unit and the number of victims at each unit. Multiobjective based resource allocation has been used in operational research fields, which mainly deals with decision making based on multiple criteria at a given time. F. Fedrick et al. [26] have described an optimized resource allocation in an emergency situation for handling earthquake-like situation. It focuses on optimized resource allocation for the search and rescue period.

In case of a limited number of resources, along with resource allocation, there is a need for resource scheduling for providing required resources to different tasks or activities which must be completed over a predefined time. The scarcity of resources may delay the relief work and may create adverse situations while performing postdisaster activities. Resource scheduling is needed when the number of available resources is less and the demand is more. Resource should be scheduled in such a way that all tasks must be completed in minimum time and there is a minimum loss of human lives.

Conventional resource scheduling approaches are generally divided into preemptive [27] or nonpreemptive [28, 29] approaches, respectively.

During postdisaster management, different tasks need to be scheduled. Various tasks may have different priorities. In priority-based task scheduling, each task is assigned a priority. Thus, the more important task is executed first. Naturally, priority-based task scheduling [30] provides better performance while dealing with postdisaster activities [31]. While allocating and scheduling the different resources, it may happen that the deadlock situation arises and starvation for resource occurs. The Banker's algorithm has been used for avoiding the deadlock for different applications [32–34]. In [32], the Banker's algorithm has been used for ensuring finite turnaround time for different jobs. The disadvantage of this approach is that it does not take care of resource utilization. In case of critical response and recovery operations, it is mandatory to have an efficient resource utilization due to a limited number of resources and a large number of regions needing the relief operation. In this view, the method proposed in this paper considers both issues, the scheduling and utilization of resources, simultaneously. The approach based on Banker's algorithm has been described in [33] for improving utilization of automatic guided vehicles through the proposed scheduling policy. In a real-time application, the demand and availability of resources should be considered for scheduling and allocating the resources. Our proposed method considers the demand and availability of resources while scheduling and allocating them to a different task in an optimized way. In [34], resource provisioning algorithm based on Banker's algorithm has been described for multi-access edge computing. In this paper also the main goal is to avoid a deadlock situation. It also considers overdemand and delays while provisioning the resources. In disaster management, there are several tasks to be completed based on an emergency, the tasks must be performed in particular order, and accordingly resources must be scheduled and allocated. Our proposed algorithm takes care of this by assigning the priority to each task, and priority-based resource allocation and scheduling help in handling several tasks efficiently.

As discussed in the literature survey, a number of methods have been reported for scheduling jobs and utilizing the resources. In the case of a limited number of resources, the resource scheduling is very much necessary. In this context, there is a need for developing the method which takes care of various important tasks and performs the allocation and scheduling of resources by considering various objectives and criteria. There are a number of issues like executing the tasks based on their importance, completing all task as early as possible, and completing all tasks with minimum cost. In this paper, we take care of these issues, which differentiates our proposed method from other techniques reported in the literature. We propose multiple objectives based resource allocating and scheduling algorithm for performing different tasks on hand with priority. The proposed method is evaluated based on the completion time of different tasks and the utilization of resources. Overall, using our proposed algorithm, the performance of the system is improved in terms of the number of parameters, namely, fair allocation of resources, utilization of resources, and time for completing a particular task at the different places simultaneously.

3. Proposed Resource Management Approach

In this section, the proposed approach for resource management is presented. The novelty of the proposed algorithm is as follow. From discussion in the literature survey, there is a need for an efficient method for resource allocation and utilization. Several tasks need to be completed based on their importance in a particular order. So assigning the priority to each task and accordingly allocating and scheduling the resources are very important. For achieving this, there may be several objectives that must be fulfilled. In this context, this paper introduces the novel algorithm for resource allocation and scheduling based on priority using multiobjective based criteria for completing the different tasks efficiently. When a disaster occurs, multiple places are affected. To handle such a situation, the rescue and recovery operations must be carried out in an effective manner. For rescue and recovery operations, various activities or tasks must be planned and executed accordingly. For executing these activities or tasks, various types of resources are required for completion. So there is a need to distribute the number of resources to these tasks or activities in time. Each task or activity may need the different type of resources and, hence, it is important to allocate the required number of resources at each place for completion of the tasks or activities on time, which may help to minimize fatality. The above discussion may be visualized through a postdisaster management workflow as depicted in Figure 2. Assume there are N disaster-affected places. These places are represented as a set $\mathscr{P}$ given by

$$\mathscr{P} = \{P_1, P_2, P_3, \ldots, P_N\} \tag{1}$$

where P_i is i^{th} place in the affected area for $i = 1, \ldots, N$. Assume that there are M number of warehouse centers represented by $\mathscr{W}$ such that

$$\mathscr{W} = \{W_1, W_2, W_3, \ldots, W_M\} \tag{2}$$

where W_j is specific j^{th} warehouse located on the field where relief work is carried out for $j = 1, \ldots, M$. The warehouse center is basically a storage house for different resources. Each warehouse has K different types of resources, where K varies from one warehouse to another. The number of these resources are represented as a set $\{R_1, R_2, R_3, \ldots, R_K\}$ at a particular warehouse. For representing the number of resources of a particular type located at a specific warehouse, the symbol R_{jk} is used to indicate the number of resources of type k located at j^{th} warehouse.

At each disaster place, there is a need to carry out certain number of tasks. These tasks are denoted by $\{T_1, T_2, T_3, \ldots T_n\}$. To carry out these tasks, different types of resources are required. There is a possibility that the demand at different places may be more as compared to the available number of resources, or it may be less than the total number of available resources. In brief, there may be an overdemand or underdemand for resources. The

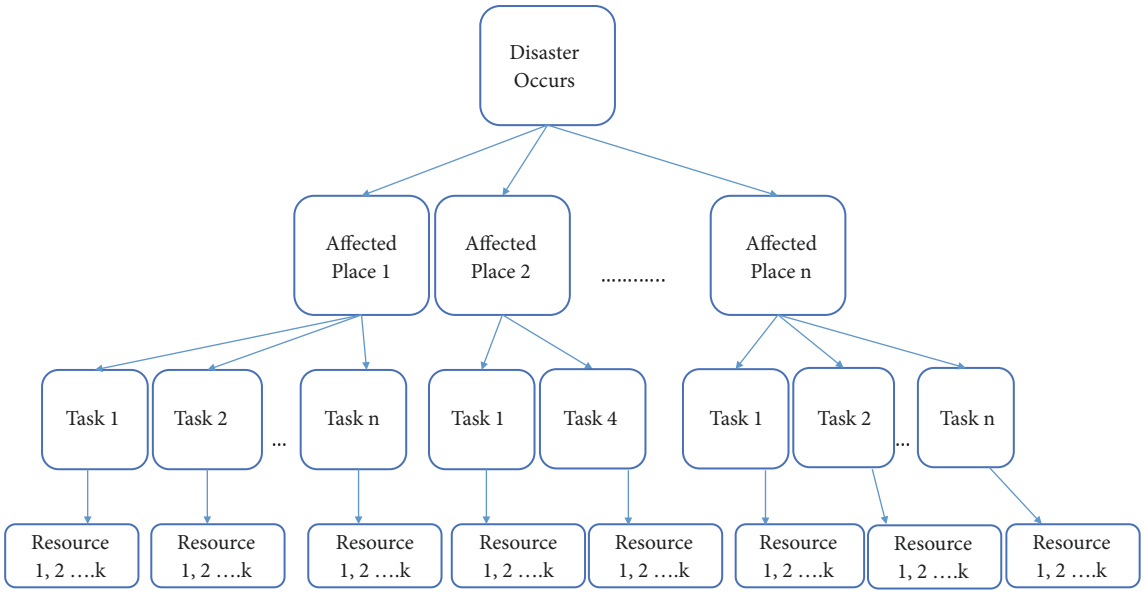

Figure 2: Disaster management workflow.

proposed method for resource management must consider this aspect. In case of overdemand for different resources, i.e., a demand for resource is more than its availability, the resource management process is divided into two phases: *resource allocation* followed by *resource scheduling*, while in case of underdemand for resources there is only one phase, i.e., *resource allocation*. The demand for a particular resource of type k at place i is D_{ik} and the number of resources of type k available at warehouse j is R_{jk}. Using these notations, overdemand and underdemand for resources are depicted in the form of equations shown below. Equations (3) and (4) depict the overdemand and underdemand, respectively.

$$\sum_{i=1}^{N}\sum_{k=1}^{K} D_{ik} \geq \sum_{j=1}^{M}\sum_{k=1}^{K} R_{jk} \tag{3}$$

$$\sum_{i=1}^{N}\sum_{k=1}^{K} D_{ik} < \sum_{j=1}^{M}\sum_{k=1}^{K} R_{jk} \tag{4}$$

Based on the conditions mentioned in (3) and (4), both activities, namely, resource allocation and scheduling, need to be carried out, or only resource allocation is performed.

3.1. Resource Allocation. Resource allocation is a systematic approach for assigning the resources as per the requirement. As mentioned earlier, postdisaster management needs to accomplish various tasks for fulfilling different objectives set as part of the rescue and recovery operation that is carried out. In this context, it is desirable to have a method which takes care of these objectives while allocating resources. In this view, we propose a multiobjective based resource allocation scheme. Multiobjective based allocation scheme decides how many resources must be allocated from which warehouse to the disaster place. Naturally, the proposed scheme should allocate resources in the first phase in such a way that the number of resources should be distributed to those places having maximum requirement and priority of an activity or tasks to be performed. In this view, for fulfilling multiple objectives, we introduce various parameters. These parameters help in defining the multiobjective functions for accomplishing various tasks of rescue and recovery operation.

For rescue and recovery operation, it is very important that various tasks or activities must be carried out in time to reduce postdisaster fatalities. In this context, we consider mainly four parameters. There are a number of tasks to be performed and each task may have a different amount of urgency. It is preferable to assign priority to different tasks. So the first parameter is proportional priority. Second, the resources should be availed in minimum time at the required place. The resources may be distributed from various warehouses located at different places as stated earlier. So the second parameter is the transportation cost. The third parameter is resource utilization as each resource must be utilized to its maximum capacity. In the case of a limited number of resources, the scheduling is required so that the resources will be available for different tasks wherever it is required. In this view, the fourth parameter is scheduling time. These parameters are defined and discussed in detail as follows.

3.1.1. Proportional Priority. For handling the postdisaster situation, the main goal is to reduce fatality. For example, there is a mass destruction due to the collapse of several buildings in disaster-affected region, there are a number of people injured at different locations, and now a number of ambulance vehicles are required for shifting these injured people from different places to the nearby medical center for treatment. In such a situation, these places need to be served

first with high priority to reduce fatality. As there may be such several places and the number of injured people may vary from one place to another, it is required that carrying vehicle should be available at a particular place first, where there is more number of injured people compared to the place where there is less number of injured people. This aspect can be incorporated by assigning the priority proportional to the requirement of the resources. For algorithmic description, the number of injured people who need the service of an ambulance is represented as an entity count. This entity count needs a service of a particular resource. That is, *ECS* (entity count for a service or resource) represents entity count as the number of injured people for the example cited here. For assigning proportional priority to a particular service at specific location i, $Priority_i$ is defined as

$$Priority_i = \frac{ECS_i}{\sum_{i=1}^{i=N} ECS_i} \tag{5}$$

where $Priority_i$ is priority value at disaster-affected place P_i and ECS_i represents the entity count at location i or place P_i that needs the service of a particular resource. The proportional priority is normalized with respect to the count of entities at all places in the disaster-affected region.

3.1.2. Transportation Cost. During rescue and recovery operations, the resources are distributed from warehouses to different places in the disaster-affected area. To reduce the fatality, the resources should be provided as quickly as possible. It is quite possible that the roads may be damaged due to the disaster. So identifying the route to the desired location for supplying the resources in shortest span of time is mandatory. The route identified should be such that the transportation time is minimum. In this context, in our proposed algorithm, the transportation cost is incorporated as one of the parameters. The transportation cost is evaluated based on the time and existence of the route to desired location. Drones, developed under the research grant as mentioned in the Acknowledgments, help in capturing images and hence identifying the existence of the route. In case of availability of network access, our proposed system identifies this route through Google Maps.

The existence of the route is represented as reachability between disaster-affected place and warehouse. The reachability is set to 1, if a route exists; otherwise it is set to 0, as shown in (6).

$$Reach_{ij} = \begin{cases} 1, & \text{if route exists between place } P_i \\ & \text{and warehouse } W_j \\ 0. & \text{Otherwise} \end{cases} \tag{6}$$

The objective is to minimize the transportation cost so that the resources should be available in minimum time to the disaster-affected places. Based on this assumption, the objective is defined as

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} transportation\_cost_{ij} * Reach_{ij} \tag{7}$$

where the $transportation\_cost_{ij}$ is measured in terms of time and distance between the affected place P_i and the warehouse W_j.

3.1.3. Resource Utilization. Another parameter chosen for defining multiobjective based problem formulation is based on the utilization of resources. For rescue and recovery operations, the availability of resources is always critical. It is desired that various resources should be utilized maximally. In this context, the following objective is maximized for achieving maximum resource utilization. The same criteria may be stated in a different view, i.e., serve the maximum number of disaster-affected places with a minimum number of resources. Indirectly, each resource utilization is maximal. Maximal resource utilization can be achieved considering the demand for resources of type k, at affected place i, and with available number of resources that should be allocated at place i for a specific task. It may happen that there are a number of tasks to be performed at place i. Each of these tasks may have a different priority, i.e., proportional priority defined in (5). Thus, some of the tasks may have higher priority compared to other tasks at the same place. The number of such tasks may also vary from one place to another place. In this view, the different places are also assigned priority given by *Place_Priority*, which are defined in terms of the number of tasks with higher priority. If the number of tasks requiring resource type k has high proportional priority, then the *Place_Priority* is higher for that resource type. The *Place_Priority* at place i for resource type k is defined as $Place\_Priority_{ki}$. The resource utilization is measured in terms of available resources based on the number of tasks with their respective priorities which need these resources and the priority of place are defined as above. The objective is to maximize resource utilization using the following equation:

$$\max \frac{\sum_{i=1}^{N} \sum_{k=1}^{K} D_{ik}}{\sum_{j=1}^{M} \sum_{k=1}^{K} R_{jk}} * Priority_i * Place\_Priority_{ki} \tag{8}$$

where $Place\_Priority_{ki}$ is a priority of place i for resource type k.

3.1.4. Scheduling Time. It is important to accomplish various tasks of rescue and recovery operations in time. These tasks need different resources. It may happen that the resources may be limited in number. So, it is required to schedule different tasks and allocate the resources to these tasks. Indirectly various resources should be scheduled for different tasks in a way that all tasks may be completed in time. It is also important that the scheduling time should be minimum. In this view, minimizing overall scheduling time is one of the parameters that our algorithm achieves through multiobjective based formulation. In our proposed system, the program evaluation and review technique (PERT) [35, 36] is used to analyze scheduling time, so that in minimum time more number of places can be served and the required number of tasks may be completed. So the objective is to minimize the overall scheduling time at place i. This

minimum time value, $Time_i$ [35], is given by the following equation:

$$\min Time_i = \frac{[O_t + 4M_t + P_t]}{6} \tag{9}$$

where O_t is an optimistic time to accomplish a particular task assuming that everything goes well on time as normally expected, i.e., the best condition. $4M_t$ is the most likely time, i.e., the best estimated time in which task may be completed, and P_t is the pessimistic time which is the maximum possible time taken to complete task considering the worst scenario, i.e., when everything goes wrong.

Multiobjective Based Allocation. Using the four parameters described above, namely, proportional priority, transportation cost, resource utilization, and resource scheduling time, the multiobjective function is evaluated. The multiobjective function provides an optimal value of the decision variable, represented as $Volume_{ikj}$. The decision variable $Volume_{ikj}$ is the number of resources of type k to be allocated from a particular warehouse j at location i to accomplish a particular task based on its priority in minimum time. Formally, the decision variable is defined as

$$\begin{aligned} &Volume_{ikj} \\ &\quad = \min(\text{transportation cost, scheduling time}) \\ &\qquad + \max(\text{resource utilization}) \end{aligned} \tag{10}$$

subject to

$$Volume_{ikj} <= D_{ik} \tag{11}$$

$$Volume_{ikj} <= R_{jk}. \tag{12}$$

It is important to note that the number of resources of type k that can be allotted at place i from warehouse j should not be greater than the number of resources of type k available at warehouse j. Similarly, the number of resources of type k allotted for a particular task at place i should not be greater than the demand for the same resource at the same place. Both these conditions are defined as constraints in (10) of multiobjective based evaluation.

3.2. Resource Scheduling. As discussed earlier when the demand for resource is more as compared to the availability of resources, the scheduling of the resources is required for completing various tasks. The resource scheduling needs to be carried out considering various parameters and the availability of resources so that different tasks must be completed in time as per their importance. In disaster management, resources are scheduled based on the priority of tasks and urgency of a place in the required time. In this context, it is important that the places which are not served yet need to be served first as part of resource scheduling to avoid starvation of resources or delay in rescue and recovery operations. For our proposed algorithm, for formulating the problem based on multiobjective based criteria, we use TOPSIS [37–39]. TOPSIS provides the ranking based on a set of parameters for scheduling the resources at nonallocated places for completing various tasks. These parameters are considered as scheduling parameters or criteria. The values of these parameters are of two types, classified as benefit parameters and cost parameters. The number of benefit parameters and cost parameters may vary from one application to another. The benefit parameters are set to the number of entity count (ECS) of a different category. For postdisaster management scenario, there may be a scenario where the number of injured people should be shifted from the disaster location to nearby medical center through ambulance; then $parameter_i$ is the count of entities of a particular age group. The idea is to provide service to a lower age group first compared to the higher age group of people. Similarly, the cost parameters are defined. For postdisaster management, in our case, two cost parameters are defined, namely, the evacuation time and transportation cost. Using these parameters, TOPSIS calculates the ranking for nonallocated places for scheduling the resources. In this context, various variables and symbols used by TOPSIS are described below for narrating the proposed resource scheduling algorithm.

Notations

(1) *allocated_places*: Set of places where resources are already allocated.

(2) *non_allocated_places*: Set of unserved places, where resource demand is not satisfied or partially satisfied.

(3) $Scheduling\_index_i$: Scheduling rank calculated for each unserved places.

(4) $need_{ik}$: Need of resource type k at disaster place i.

(5) $Parameter = \{parameter_1, parameter_2, \ldots, parameter_m\}$ is a set of scheduling parameters or criteria as discussed above.

(6) Using the above parameter values at different disaster location, scheduling index matrix α is created which is called the decision matrix as it is used for scheduling decision.

$$\alpha_{ij} = \text{Non\_allocated\_places} \begin{array}{c} \text{parameters} \\ \begin{bmatrix} \alpha 11 & \ldots & \alpha 1m \\ \vdots & \ddots & \vdots \\ \alpha n1 & \ldots & \alpha nm \end{bmatrix} \end{array} \tag{13}$$

α is the decision matrix for scheduling index.

Each entry of α matrix is α_{nm}, indicating the value of parameter m which is used for resource scheduling at nonserved place n.

(7) Each parameter described above is assigned a weight value based on the urgency of the group represented by particular parameter. For this weight vector W is defined.

$W = \{w_1, w_2, \ldots, w_M\}$ is weight vector, where w_m is a weight assigned to parameter $parameter_m$. These

weight values are assigned for the above parameter set at each nonserved place n.

(8) Using the above weights, the β matrix is defined where each entry β_{nm} is normalized weight value, i.e., for parameter m at nonserved place n.

(9) $Available_{jk}$: Currently available resource of type k at warehouse j.

(10) $Allocation_{ik}$: Resource of type k allocated to disaster place i.

(11) I': A set of values associated with benefit parameter. The benefit parameter may be the number of entities served as defined above. In general, benefit parameters are those parameters which are associated with an entity that is benefited in terms of different services.

(12) I'': A set of values associated with cost parameter which is described above. The time of completion of a particular task and the distance from warehouse to an affected place are such parameters which affect the completion of different tasks performed as a part of rescue and recovery operation.

(13) Dt_i^+: Positive Euclidean distance from ideal solution.

(14) Dt_i^-: Negative Euclidean distance from ideal solution.

Equation (14) denotes the set of places which are not served. These are places where the resources are not allocated yet or a partial number of resources are allocated and, hence, these places need to be served as soon as possible. So these are places still in need of resources.

$$non\_allocated\_places = \mathscr{P} - allocated\_places \tag{14}$$

After a phase of resource allocation as per the multiobjective function in (10) as described in the previous section, it may happen that there are a number of places left, where the particular types of resources are not allocated due to the limited number of resources. For representing the need for a particular resource of type k at place i, the following variable is defined by (15).

$$need_{ik} = D_{ik} - Volume_{ikj} \tag{15}$$

The above equation calculates the quantity of resources of type k still needed at disaster places i.

Using the multiobjective based resource allocation method as mentioned above, some places are served but there are unserved places where still resources are needed to be allocated. For handling such situations, using TOPSIS technique as described above, *Scheduling_index* is calculated and assigned to each of nonallocated places, considering multiple parameters.

Steps for Evaluating Scheduling_Index

(i) Step 1: Normalize Decision matrix.

The decision matrix is normalized using standard technique mentioned as below.

$$r_{mn} = \frac{\alpha_{mn}}{\sum_{m=1}^{M}\left(\left(\alpha_{mn}\right)^{1/2}\right)} \tag{16}$$

(ii) Step 2: Construct weighted matrix.

$$\beta_{mn} = w_m * r_{mn} \tag{17}$$

(iii) Step 3: Determine positive and negative ideal solution.

(a) Positive ideal solution identifies the best ideal solution by maximizing benefit parameters and minimizing the cost parameters.

$$\begin{aligned} A^+ &= \{\beta_1^+, \beta_2^+, \ldots, \beta_n^+\} \\ &= \left\{\left(\max \beta_{mn} \mid m \in I'\right), \left(\min \beta_{mn} \mid m \in I''\right)\right\} \end{aligned} \tag{18}$$

(b) Negative ideal solution maximizes the cost parameter and minimizes the benefit parameter.

$$\begin{aligned} A^- &= \{\beta_1^-, \beta_2^-, \ldots, \beta_n^-\} \\ &= \left\{\left(\min \beta_{mn} \mid m \in I'\right), \left(\max \beta_{mn} \mid m \in I''\right)\right\} \end{aligned} \tag{19}$$

(iv) Step 4: Calculate separation measure using Euclidean distance. Here, Euclidean distance from a positive solution to the ideal solution is calculated as well as from negative solution to ideal solution. The ideal solution is the solution which considers maximum satisfaction of all criteria, but such a solution is not feasible in a restricted environment. The separation measures are calculated as below using positive and negative ideal solutions.

$$Dt_i^+ = \sqrt{\sum_{m=1}^{M}\left(\beta_{mn} - \beta_n^+\right)^2} \tag{20}$$

$$Dt_i^- = \sqrt{\sum_{m=1}^{M}\left(\beta_{mn} - \beta_n^-\right)^2} \tag{21}$$

(v) Step 5: Calculate $Scheduling\_index_n$.

The $Scheduling\_index_n$ represents the relative closeness to ideal solution.

$$Scheduling\_index_n = \frac{Dt_n^-}{Dt_n^+} + Dt_n^- \tag{22}$$

Arrange *Scheduling_index* in descending order.

The pseudo code of proposed resource management approach and resource scheduling approach is mentioned in Algorithms 1 and 2, respectively.

The resources must be allocated and scheduled efficiently. The demand for different resources at each place must be satisfied without any deadlock situation and starvation. Hence, scheduling should be done in such a way that different tasks must be completed in order of their importance. Moreover, it is desirable that all resources must be utilized maximally. In this context, the demand satisfaction, percentage utilization of resources, and overall completion of different

(1) **Input**: Set of Disaster Places: P_i, Set of Warehouse Centers: W_j, Quantity of Resource Type k at Warehouse Center j: R_{jk}, Demand of resource type k at each disaster place i: D_{ik}
(2) **Output**: Quantity of resource of type k that should be supplied from warehouse Center to disaster place.
(3) **Procedure**
(4) **if** $\sum_{i=1}^{N} \sum_{k=1}^{K} D_{ik} \geq \sum_{j=1}^{M} \sum_{k=1}^{K} R_{jk}$ **then**
(5) Resource_Allocation()
(6) Resource_Scheduling()
(7) **else**
(8) Resource_Allocation()

Algorithm 1: Resource management (RM).

(1) **Input** Number of warehouse centers, Available resources at warehouse centers, Allocated resources to task, $Scheduling\_index_i$
(2) **Output** Scheduling of resource for a particular task at all non-allocated places
(3) Step 2: Sort the $Scheduling\_index_i$ in descending order.
(4) Step 3: Allocate the resources to all *non_allocated_places* as per order of $Scheduling\_index_i$.
(5) **while** till every $non\_allocated\_places_n$ has served resources **do**
(6) **if** $Need_{ik} \geq Available_{jk}$ **then**
(7) Go for next *non_allocated_places*
(8) **else**
(9) ▷ Verifying the availability for the resource type k
(10) $Available_{jk} = Available_{jk} - Need_{ik}$
(11) ▷ Allocating the requested resources for *non_allocated_places* i
(12) $Allocation_{ik} = Allocation_{ik} + Need_{ik}$
(13) Add the served resources
(14) Return resource schedule

Algorithm 2: Resource scheduling.

tasks are considered as performance measure parameters. These parameters help in comparing our proposed method with other existing methods. In the simulation results as mentioned in Section 4, these three parameters are evaluated compared with the existing approaches.

4. Result and Analysis

For evaluating the proposed method, the scenario is synthesized using the number of actual places of our city, Surat, located in Gujarat state in India. The disaster places are demonstrated through Google Maps using the Android application developed for visualizing the outcome using our approach. As pointed out earlier, for postdisaster management, completion of various tasks in particular order in minimum time is very important. For completion of these tasks, resources must be allocated and scheduled accordingly. At the same time due to a limited number of resources, it is desired that available resources must be utilized optimally. In this context, the proposed method is evaluated with respect to three parameters, demand satisfaction, percentage utilization of resource, and overall completion time of different tasks altogether. The demand satisfaction means that a percentage of demand for a particular resource type is satisfied or provided at all the places. Percentage utilization of resource depicts how efficiently the algorithm utilizes the resources. With proposed resource allocation and scheduling, it is desired that the overall completion time of different task must be minimum or fast enough compared to the normal sequential way of completing the different tasks.

The proposed multiobjective based resource allocation and scheduling algorithms are implemented in LINGO [10]. The results are visualized using an Android application using Google Maps. For demonstration, our local city, Surat, region is considered. The complete Surat city region is divided into seven zones by Surat Municipal Corporation (SMC). These regions are shown in Figure 3. For simulating and visualization of the proposed algorithm, it is assumed that various parts of different zones are affected by some massive natural disaster. It is assumed that there are seven warehouse centers, one in each zone. There are ten different areas or places affected by the disaster. At each place, the number of tasks to be performed as part of rescue and recovery operation is decided by the management authority. There is a demand for a certain type of resource at each place. For instance, these resources may be an ambulance, fire vehicle, emergency vehicle, rescue boat, food packages, medical container, etc. For example, there is a demand for a particular type of resource, say, ambulance. There are number of injured people, which are entities, requiring the service of shifting to nearby place by the medical center from disaster-affected place. For such a typical scenario, the demand for particular resource at different places with their priority along with entity count is shown in the Table 1.

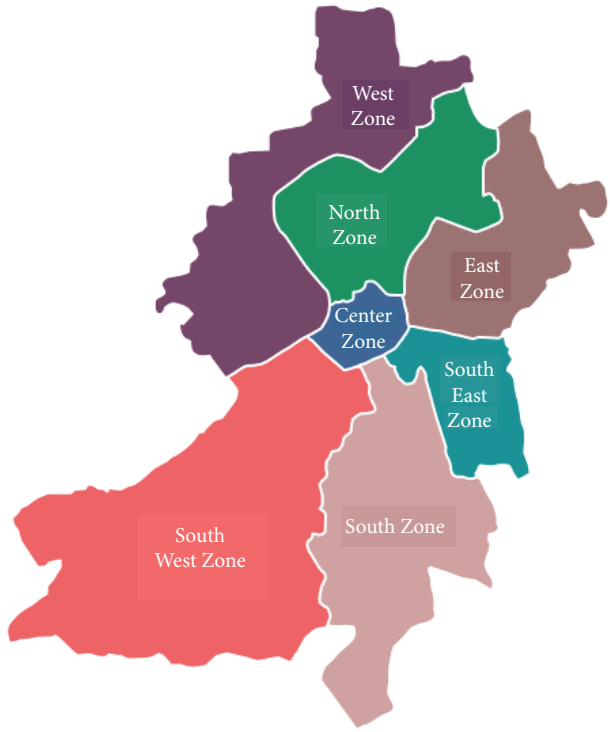

Figure 3: Zone-wise division of Surat city [6].

Table 1: Demand of resource, ECS, and *Place_Priority*.

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Demand at each place D_{ik}	100	37	22	32	41	32	43	38	50	70
Entity Count requires Service (ECS)	400	50	40	300	406	500	470	600	600	800
Place_Priority	1	1	1	2	1	1	2	2	2	2

Table 2: Quantity of resources at each warehouse.

Warehouse Center	W_1	W_2	W_3	W_4	W_5	W_6	W_7
Quantity of Resources R_{jk}	60	55	51	43	41	52	20

Table 3: Route (reachability) from disaster affected place to warehouse center.

$Reach_{ij}$	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
W_1	0	1	1	1	1	1	1	1	1	0
W_2	1	1	1	1	1	1	0	1	1	1
W_3	1	1	1	1	1	1	1	1	1	1
W_4	1	1	0	1	1	0	1	1	1	0
W_5	1	1	1	1	1	0	1	1	1	1
W_6	0	0	0	1	0	1	1	1	1	1
W_7	0	0	0	1	0	1	1	1	1	1

It is important to note that the scenario described here is a very typical one considering all types of situations. In Table 1, at place P_1 the demand is more but ECS is less compared to other places like P_4 to P_{10}. In the given scenario, all entities are injured people who need medical service. Further, all these entities are distributed over different age groups. Our allocation and scheduling algorithm exploits this information while allocating the resources at different places. As mentioned in the algorithm description, the allocation of different resources is based on an evaluation of multiobjective function using different parameters. One of the parameters is a place priority which is based on ECS. The demand is decided by the urgency of resource requirement. As entities are distributed over different age groups, the urgency may vary from one group to another. So it may happen that ambulance service is not required by all groups of entities but only a few entities among these groups require an ambulance service, which are severely injured, and hence the demand is less though ECS is more at places like P_4 to P_{10}.

As mentioned earlier, each warehouse center has different types of resources. The number of resources of type k at warehouse center j is represented by R_{jk}. In Table 2, the number of resources of a particular type available at various warehouse center is mentioned.

The reachability from each disaster-affected places to the warehouse center is shown in Table 3. If a route exists from the warehouse center to disaster-affected place, then it is

indicated by 1. If a route is damaged or having congestion, then it is not possible to reach the place through this route and, hence, it is indicated by 0.

In Figure 4, the distance from disaster-affected place to nearby warehouse center is shown using Google Maps for visualization. Here, latitude and longitude are mapped in a 2-dimensional coordinate system to calculate the distance for further processing. In Figure 4, the upper part of image represents latitude and longitude on y-axis and x-axis, respectively. The place and warehouse are indicated by red dots whereas the distance among these place and warehouse in meters is displayed in the lower part of the same image with blue dots for place and warehouse.

First, the result of resource allocation is described and it is followed by the result and analysis of the resource scheduling. Multiobjective approach is implemented in LINGO [10] and compared to the existing approach [15] for resource allocation. Figure 5 displays the comparison of allocation of a particular type of resource at different places using our proposed approach in this paper and existing approach [15]. In Figure 5, the demand for a particular resource at each disaster-affected place is shown using yellow color. The resource allocated by our proposed approach, which is the value of decision variable $Volume_{ikj}$ derived using (10), is shown with magenta color. The resource allocation by the existing approach [15] is displayed using green color. In [15], for allocating the resources, it considers priority and cost matrix, also considering the number of injured people. In our case, multiple objectives are considered as mentioned in (10) and have used proportional priority for the places, based on entity count (ECS) which requires service. We have also considered the scenario of overdemand as well as underdemand for resources. Further, it is worth mentioning that the category of ECS based on the age group to determine the urgency is also incorporated to evaluate place priority along with other objectives as described earlier.

The scenario considered here for evaluating our algorithm has 10 places P_1 to P_{10} as discussed earlier in this section. The two-level priorities assigned are high and low. High priority is marked with 2 and low with 1 in Table 1. It also depicts the demand, i.e., the number of resources of a particular type, at places P_1 to P_{10}. The places P_4, P_7, P_8, P_9, and P_{10} are having higher priority compared to other places. From Figure 5 it is clear that the proposed approach allocates more resources to those places where priority is high. As mentioned in Table 1, the places such as $\{P_2; P_3; P_5\}$ have less priority and ECS count is also low. As these places are not that crucial, thus during phase 1, i.e., resource allocation phase, no resources are allocated to these places. At places $\{P_1; P_4; P_6; P_7\}$ partial resources are allocated, while at other places $\{P_8; P_9; P_{10}\}$ complete demand is satisfied, as these places are more important and crucial. That is, these places are served first. From simulation results, it is clear that our proposed approach serves the most affected places, where the entity count and the place priority are higher along with other objective parameters described earlier.

The performance of the resource allocation is evaluated using the demand satisfaction which indicates the total number of tasks completed, and resources are served as per demand across the different places. The demand satisfaction is calculated using (23).

$$demand\_satisfaction = \frac{\sum_{i=1}^{N} \sum_{k=1}^{K} \sum_{j=1}^{M} Volume_{ikj}}{\sum_{i=1}^{N} \sum_{k=1}^{K} D_{ik}} \quad (23)$$

Using our proposed approach 71% of demand is satisfied, while in the existing approach [15] this value is 65.1%. It shows that our approach satisfies demand at more places as compared to the existing approach. The resource allocation based on multiple objectives using priorities of tasks and places is most effective for rescue and recovery operations.

Another parameter for evaluating the performance of resource algorithm is to find out whether the resources are utilized optimally or not. It is possible to measure this using percentage utilization of particular resource. Figure 6 represents the percentage utilization of resource from each warehouse to different disaster places. As mentioned in Tables 1 and 2 there are 7 warehouse centers and 10 places that are affected by a disaster. The sum of all percentage values is 100, that is, 100% utilization of the resource. The meaning is that, from different warehouses, all the available resources of a similar type are completely utilized at different places. From this figure, it is clear that using our proposed algorithm the resource utilization is 100% which is the most desirable. This is possible because of multiobjective based allocation. Figure 6 shows the percentage of resource allocation from each warehouse to different disaster places.

The proposed approach is compared with the existing approach of resource allocation [15] in which the same set of input is given to both the existing allocation approach and the proposed allocation approach. Our proposed approach considers more objectives and constraints as compared to the existing resource allocation approach [15]. As depicted in Figures 5 and 6, the proposed approach first serves more needing places as compared to the existing approach [15].

As mentioned in Tables 1 and 2, respectively, the demand is more than the number of resources, so it is not possible to serve all places at the same time by allocating required number of resources. Few places still need to be served. As per (3), it is a situation of overdemand for resources, so the resource scheduling is required to fulfill the demand for completing the task. As shown in Figure 5, the disaster-affected places such as {P2; P3; P5} are completely unserved places, while disaster-affected places {P1; P4; P6; P7} are partially served. Thus, at all these places, resources are to be scheduled as per the availability. For this task, our proposed resource scheduling algorithm calculates the scheduling index based on the benefit parameters using TOPSIS as discussed in the previous section. For the scenario depicted here, the benefit parameter is measured in terms of entity count ECS which is served to reduce the fatality. For example, in the case of disaster, the benefit parameter can be measured in terms of how many severely injured people can be served. Various injured people can be further classified based on their age to evaluate the benefit parameter. The reason is that serving smaller children may have much more urgency as compared to middle aged people. The other parameter considered for evaluating the cost is transportation time.

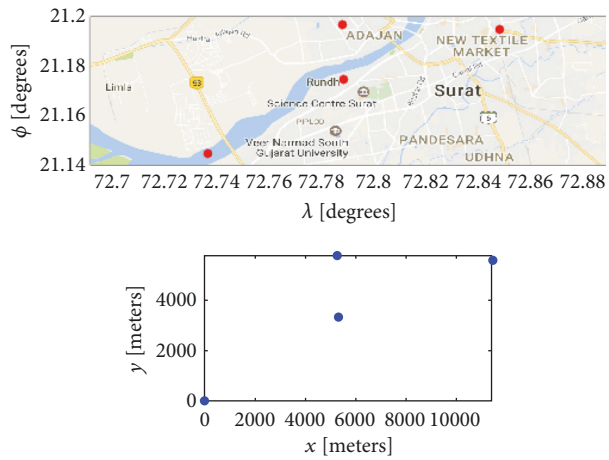

Figure 4: Distance of disaster-affected place P_4 from nearby warehouse.

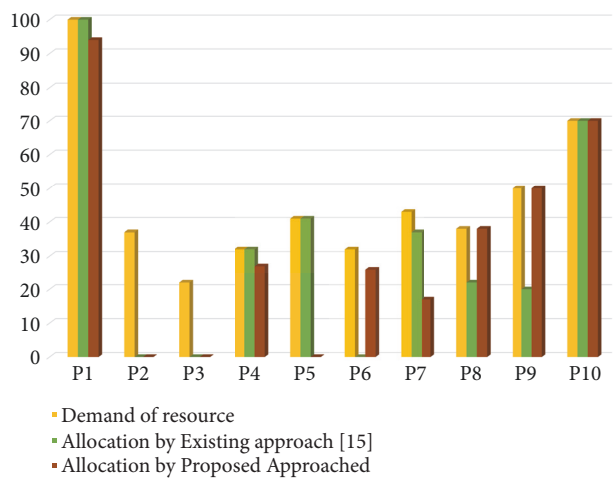

Figure 5: Comparison of resource allocation as per demand.

The third parameter which is evaluated for comparing the performance of the proposed algorithm with the existing one is overall completion time of tasks at different places altogether. In the case of postdisaster management, overall completion time of a particular activity should be minimized to reduce a loss. For evaluating overall completion time all the nonserved places that need services for a particular task should be optimally scheduled. The overall completion time is compared using our proposed algorithm and the existing approach [31]. In case of our proposed algorithm, these places are scheduled using the *Scheduling_index* which is calculated using the TOPSIS technique based on various parameters as discussed in Algorithm 2.

As mentioned earlier, the benefit parameter is evaluated in terms of entity count which is to be served for reducing the fatality. In case of disaster, the benefit parameter is evaluated in terms of how many severely injured people can be served. Various injured people can be further classified into groups based on their age. The reason is that serving smaller children may have much more urgency as compared to a middle aged group of people. Similarly, the other parameter considered for evaluating is the cost parameter which is transportation time and cost. The scheduling of resources for nonallocated disaster places are performed based on *Scheduling_index* using the available number of resources. The scheduling of the service at these places is represented using Gantt chart as depicted in Figure 7. The detail description is as follows.

It is assumed that after the task is completed at any disaster place, the resources allocated to that place are returned to the respective warehouse center. For evaluating the robustness of our algorithm, we consider a typical scenario where there is a scarcity of resources; i.e., for example, only 40% of resources are available at different warehouses in total. Further, it is also assumed that the availability of resources is measured every two hours which allows dynamic scenario for resource allocation and scheduling. From Figure 5, it is observed that the places $\{P_2, P_3, P_5\}$ are completely unserved, i.e., so far no resources are allocated at these places at the end of the resource allocation phase, so these places need to be served first. For showing the efficacy of our proposed algorithm, timeline chart is presented in Figure 7 depicting the starting time and ending time of an activity or task at a

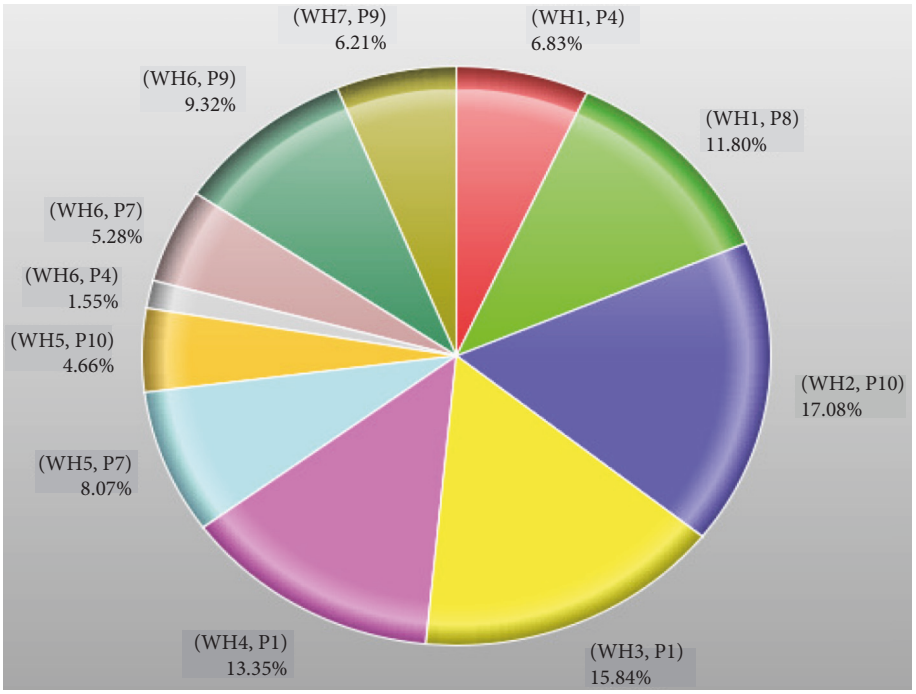

Figure 6: Percentage of resource allocation from warehouse to affected places.

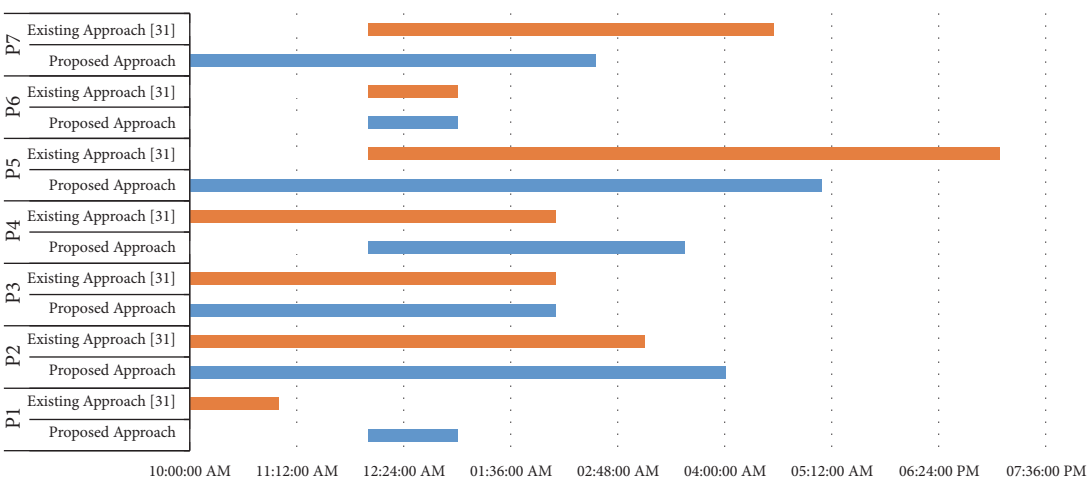

Figure 7: Gantt chart showing scheduling of nonallocated disaster places.

particular place. This represents the scheduling of resources; indirectly, it is the scheduling of activities at different places.

Let the rescue operation start at $10 : 00AM$ in the morning; at that instance the currently available number of resources at warehouse center is 129, which is 40% of the total resources available at warehouse center at the beginning of scheduling. Based on scheduling index calculated using our proposed Algorithm 2, the places $\{P_5, P_2, P_3, P_7\}$ need to be served first as they are more important places compared to places $\{P_6, P_4, P_1\}$. As shown in Figure 7, places $\{P_2, P_3, P_5, P_7\}$ are scheduled first at $10 : 00 : 00AM$, while places $\{P_1, P_4, P_6\}$ are served in the next scheduling phase. Using the existing approach [31], various activities are allocated with resources sequentially and, hence, the activities at these places are scheduled in sequence only, that is, P_1 to P_4, based on the availability of the resources. The existing scheduling approach [31] uses Bankers algorithm, while the proposed scheduling algorithm provides a rank to each unserved place based on multiple parameters using TOPSIS technique. It schedules resources considering availability of the resource and rank of unserved places, i.e., calculated using TOPSIS technique. At the same time when both algorithms perform scheduling, it is found that our proposed approach performs scheduling of all nonallocated places in 7 hours and 5 minutes, while

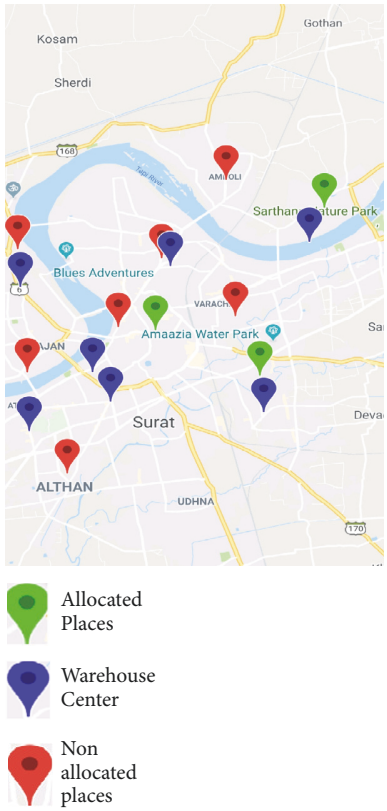

Figure 8: Visualization on Google Maps of disaster-affected places and warehouse center.

the existing approach [31] takes 9 hours and 5 minutes, i.e., the existing approach takes 2 hours more for completing the tasks.

The proposed method is also visualized using the Android application developed. The number of warehouses centers and the number of allocated places and nonallocated places are displayed using blue, green, and red color markers, respectively, using Google Maps in Figure 8. This figure represents the outcome of resource allocation phase and further scheduling is performed to all the nonallocated places.

5. Conclusion

In this paper, multiobjective based resource allocation and scheduling problems are formulated considering various parameters. These parameters allow one to assign the priority to different tasks and places depending upon the urgency of rescue and recovery operations. Using the proposed algorithm, the resources are allocated fairly at different places, in case of the demand is being more than required resources then resource scheduling is performed. Proposed resource scheduling algorithm performs successfully in terms of achieving maximal resource utilization and fulfilling the demand at various places for different tasks. The proposed algorithm is compared with the existing approach and the simulation results show that the proposed resource management approach produces better results. The current work can be extended for other parameters as per the need of different applications and the type of disaster. Also, the evaluation can be performed with more scenarios.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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