7-2012

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DOI: https://doi.org/10.1109/SOLI.2012.6273499

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***Abstract* - This paper proposes an orchestration model for post-disaster response that is aimed at automating the coordination of scarce resources that minimizes the loss of human lives. In our setting, different teams are treated as agents and their activities are "orchestrated" to optimize rescue performance. Results from simulation are analysed to evaluate the performance of the optimization model.**

Keywords: Agent-based model, humanitarian logistics, optimization, orchestration.

I. INTRODUCTION

Supply chain orchestration has its roots in a commercial setting. One such example is reported in [1] where companies join a network with a commonly agreed agenda to drive the achievement of the supply chain goals. Participating companies share a common strategy and action plan, and the design of this strategy and agenda rests upon the orchestrator who has the best understanding of customer requirements.

Humanitarian logistics involves the participation of multiple players to fulfil a common humanitarian mission. These players include international relief organizations, local and national governments, local military and the UN designated rescue forces, local and regional relief organizations, and private sector companies. It is characterised by limited resource capacity, high demand uncertainty, urgency and politicized environment [2]. Furthermore, the players' motives, missions and operating constrains are different [3]. All these characteristics make disaster relief coordination and cooperation planning a challenging task.

While extensive research has been done on business logistics orchestration, research on humanitarian logistics orchestration with the sole purpose of saving lives in disaster scenarios is still quite limited. This paper focuses on this issue and proposes a framework for humanitarian logistics orchestration. More precisely, through studying the challenges in humanitarian operations, we propose an idealized (but first of its kind) optimization model for humanitarian logistics orchestration. A simulation analysis will be presented that compares our approach with conventional heuristic decision making.

II. LITERATURE REVIEW

The study of humanitarian logistics can be divided into three levels: strategic, tactical and operational. There is also a body of work which regards humanitarian relief as a collaboration and coordination problem. At the strategic level, prepositioning relief goods in the region near some likely-to-happen locations according to historical data is discussed in [4] and [5]. Balcik and Beamon [6] discusses the number and locations of distribution centers in a relief network and the amount of relief supplies to be stocked at each distribution center. Recently for better positioning, risk-prone post-disaster scenarios are discussed by Blecken [7]. And toward comprehensive solutions, Salmeron and Apte [8] targets on minimize the total casualties by using two-stage stochastic optimization of both pre-disaster prepositioning and post-disaster operations. It is possible that up-front investment in prepositioning of the relief goods help to improve the responsiveness of the supply chain for the unpredictable event, but the cost of holding the relief goods in the supply chain should also be taken into account.

At the tactical level, Balcik, Beamon and Smilowitz [9] addresses the last mile distribution problems of the final stage of a humanitarian relief chain, and shows how the proposed model optimizes resource allocation and routing decisions; they discuss the trade-offs between these decisions on a number of test problems. Ozdamar, Ekinci and Kucukyazici [10] address the dynamic time-dependent transportation problem and provides optimal mixed (including new requests) pickup and delivery schedules for the vehicles within the current planning time horizon. Yi and Kumar [11] present an ant colony approach for solving the logistics problem involving two phases of decision making: vehicle route construction and multi-commodity dispatch, where the first phase builds stochastic vehicle paths and the second phase assigns commodities between different types of vehicle flows.

Sheu [12] addresses quick response to urgent relief by a hybrid fuzzy clustering-optimization approach involving two recursive mechanisms: disaster-affected area grouping and relief co-distribution.

At the operational level, Brown & Vassiliou [13] propose a real-time decision support system that applies optimization and simulation, and the judgment and decision are made by human operator for operational assignments as well as tactical allocation of army force units to tasks. Barbarosoglu, Ozdamar and Cevik [14] gives a mathematical model for helicopter mission planning during a disaster relief operation, which addresses not only tactical and operational level issues but also the coordination of the two levels.

Coordinating the interactions among multiple players in the relief environment is a challenging task. First, in a collaboration scenario, each of the players may have different primary motive and goal for its geographical, cultural, and organizational policies [15], this make unified collaboration between different foreign relief teams a tough job. Second, in a coordination scenario, it often fall into the anarchy of governance, more often there is a government there but with very limited relief expertise, it makes the management inefficient and eventually leads to failure. Therefore there is no single organization or government with the both the authority and expertise to cause other actors to engage in a particular coordination activity. To meet the challenges, the relief community has sought ways to improve aid coordination over the past three decades [16]. The UN and relief agencies have setup various committees and offices, such as the Office of the Coordinator for Humanitarian Affairs (OCHA), United Nations Joint Logistics Centre (UNJLC), and the Inter Agency Standing Committee (IASC), to improve coordination within the relief community. In addition, the academies also propose works to optimize and automate the relief processes as the proposed work in the first group focused on disaster relief goods pre- and post-positioning in order to better counter future situation.

While much of the works on prepositioning of relief goods and dispatching of multiple goods on multiple routes are centralized models, the challenge of orchestration to manage the interdependencies and relationships of the participant organizations is rarely addressed. There is a general lack of technical work on mechanisms to alignment the interests of different organisations, and to orchestrate the relief efforts in a scenario with scarce resources. Our research intends to bridge this gap by proposing a bidding-based orchestration model for task assignment.

III. HUMANITARIAN LOGISTICS ORCHESTRATION SCENARIO AND MODEL DESIGN

In this section, we propose humanitarian logistics orchestration model structure and define the setting of the participants in this section.

A. *Logistics Orchestration Framework*

From studying the humanitarian scenarios of the 2008 Wenchuan Earthquake [17] [18] where tens of thousands of people lost their lives, we develop the following framework. It is a three-level framework for the orchestration model as shown in Figure 1. The top level is the Master level where the orchestrator controls over the components at other levels. This is followed by Coordination level and Service level. At respective level, the components may have dependencies among themselves.

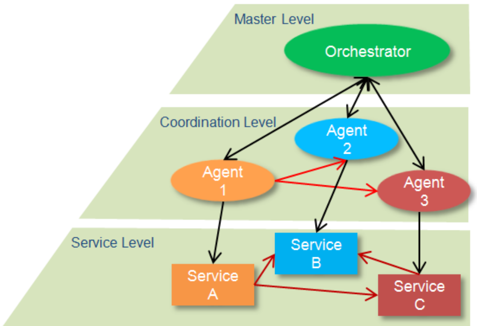

Figure-1: Framework for Logistics Orchestration

Master Level: This is the orchestration level where the orchestrator operates on a global picture of the disaster event with the information of activities and events down to the detailed resource flows. However, unlike traditional centralized systems, the orchestrator does not have absolute authority (nor full knowledge) over the resource agents; instead, it plays the role of a coordinator and may have different cooperation agreements with the other participants. The orchestrator needs the support from the agents since the information that the orchestrator possesses is always limited and the orchestrator may not know exactly when and how the agents will finish their work. In addition, the volunteers or Non-Governmental Organizations (NGOs) may not follow the orders of such an orchestrator. The other players should have the freedom to decide if they are able or want to participate in the tasks.

Coordination Level: At this level, not only the agents coordinate their activities with the orchestrator, they can also communicate with one another in accomplishing the tasks. It is difficult for the orchestrator to take charge of everything including what the agents should do once they have finished their tasks. Therefore, our framework allows the agents to broadcast their availability to the nearby workstations and ask if any work needs their help. After receiving the replies, they would choose the most suitable task among the requests.

Service Level: The agents have specialized skills, and hence the services provided by different type of agents would be different. To complete the tasks, a combination of services of multiple agents would be required. It is unavoidable that some services would have to depend on one or another because of certain limitations. For example, the victims buried underground cannot be evacuated unless the land-clearing task has been completed.

B. Orchestration Model for Humanitarian Logistics

Based on the three-level framework proposed above, we derive the following conceptual orchestration model in the humanitarian context as shown in Figure 2. In this hybrid centralized supply-chain orchestration model, the orchestrator receives disaster event reports (i.e. casualties and damages in a particular location) from the exploration teams. The reports contain the information such as when the event was identified, the location, estimated number of victims, number of victims that need to be evacuated and an estimate about the effort required to clear the land. With consolidation of the events and resources, the orchestrator will perform three consecutive steps: Event Decomposition, Selective Broadcast, and Optimization & Task Allocation. The orchestration model is designed based agent concept and will be discussed further in later sections.

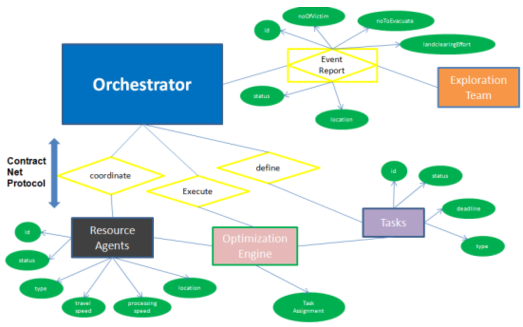

Figure 2 Orchestration Model for Humanitarian Logistics

In reality, different organizations, including government agencies, NGOs and enterprise organizations, send working teams to affected area for disaster relief. Different teams are capable of performing different rescue tasks. in our humanitarian logistics setting we categorize them into four main types, namely the exploration, land clearing, medical and evacuation teams.

All agents will share some common properties, which are "id", "type", "travel speed", "processing speed", "capacity", "status" and "location". For the same property name, it may have different meanings for different types of agents. For instance, the capacity of the evacuation team refers to the maximum victims that it can carry with, but the capacity of medical team refers to the number of members in the medical team. Each agent will be able to receive multiple task assignments that do not conflict with each other.

Each type of agent will only provide one type of service. Land-clearing teams are specialized in clearing the land; medical teams provide first-aid help and surgical operations if necessary; evacuation teams are responsible for evacuating the severely injured victims to nearby hospitals. The existing dependency is that if victims buried underground, then land-clearing must be performed first and the land-clearing task cannot be performed with other type of tasks concurrently. However, medical teams and evacuation teams can perform the task concurrently.

C. Settings of Players in Humanitarian Logistics

Due to the urgency of timing, resource constraints, and differences of organisational interests, the operations can be out of control if they are not well coordinated and managed, as experienced in relief efforts reported historically. At the same time, resources involved may come from different countries and organizations, and there are no direct command and control relationships among them. Hence it is reasonable for an organization to take the ownership of the humanitarian logistics responsibility as a whole, and play the orchestrator role to coordinate and handle the humanitarian logistics issues. For this to work, it is important to define the orchestrator and functional teams who carry the concrete tasks.

A. The Orchestrator

As the key player of the humanitarian logistics network, the roles of orchestrator include: 1) Architect design and manage the logistics network. It takes leadership to pull together resources of other players; 2) Coordination & Control: takes control through empowerment to plan and assign the tasks to the work teams. It will balance the work of the work team agents in the logistics network. The orchestrator also coordinates the tasks to managing the interdependencies. 3) Identification and integration: The orchestrator classifies and identifies the value of the team resources and integrates their values into the logistics network. The orchestrator will also identify critical resources which are of high value to the network, and create new value through well organisation and integration of resources.

B. Exploration Team(s)

Exploration teams are responsible for exploring the affected disaster site to look for victims. First aid kits with basic medical supplies are carried by them so that victims can get first-aid treatment when they are found. Exploration teams identify the events and may trigger a new set of tasks for all other work teams. When victims are found, an exploration team is responsible to estimate the situation and send back the necessary information to the orchestrator, who will then consolidate and analyse messages received from different exploration teams, plan and assign tasks to selected agents. The necessary information includes: exact location where the event happens; number of victims found; whether landing clearing is needed; (if yes) what the workload will be so that the duration needed to clear the land can be estimated to facilitate other operations; Whether evacuation is needed, and (if yes) how many people need to be evacuated.

While other information needs to be estimated by the exploration team, the location of the event can be automatically traced using the site where the message is sent from through the Global Positioning System (GPS) via their mobile devices. The exploration teams will leave the site and continue searching for victims once they have reported the information and provided first-aid treatment to the current found victims to their very best efforts. They work relatively independently from other teams, and the main interaction is with the central processor.

C. Land Clearing Team(s)

Land-clearing teams clear the land where victims are found buried under disaster wreckage so that the victims can be physically rescued. If land clearing is necessary, then the medical or evacuation teams may not be able to start working until land clearing team finishes clearing the field and get victims out from the wreckage. The arrival time of medical team and evacuation team thus depends on whether victims are buried underground or unburied and waiting for help. In reality, to clear the wreckages, usually large equipment and heavy vehicles are required. Some equipment may not work without power supply. However, in our setting, we will assume that this is a local issue and will somehow be resolved. The only factor that will affect the assignment of tasks to agents in the system is the teams' availability, location and work capacity.

D. Medical Team(s)

Medical teams specialize in medical treatment of victims. In the case where a victim needs medical treatment in addition to first-aid treatment, a medical team will be called. Whether a medical team should arrive right after a call from the exploration team, or only after land clearing team rescues the victims depends on the information sent from the exploration team. In our setting, we assume that medical teams are always needed. If necessary, victims may be transferred to some temporary shelter area. However, we would assume that the place is very close to the site where victims are found and that the distance is negligible.

E. Evacuation Team(s)

If there are victims with severe injuries, they need to be evacuated to hospitals or places with more advanced medical supplies and support. The evacuation process will be carried out either by land transport or helicopter, depending on both the subjective condition for transportation as well as the degree of severity of the victims. Helicopters are scarce resource since they are limited in both number and capacity, and cars are limited to access certain region by road condition. Thus it may be a difficult to decide which evacuation method to use. In our setting, each of the different teams will carry a portable device through which they will be able to communicate with the orchestrator and other agents. Global Positioning System (GPS) should be available so that location can be instantly tracked. A list of tasks to perform will be available, and details of each task, such as time and place to go to next, will be readable once accessed.

IV. Orchestration Optimization Model

A. Task Bidding and Allocation

Once an exploration team reports an event, the orchestrator will, based on the information provided, decompose the event into different tasks for the different functional teams. After sorting each task according to the deadline and temporal relationships with other tasks (for example, an evacuation task must occur after the land clearing task for an event), the orchestrator will then decide how to accomplish the tasks with the objective of minimizing loss of lives.

Each agent will first register with the orchestrator to indicate their availability. The protocol for the coordination of agents and optimization of task allocation as depicted in Figure 3.

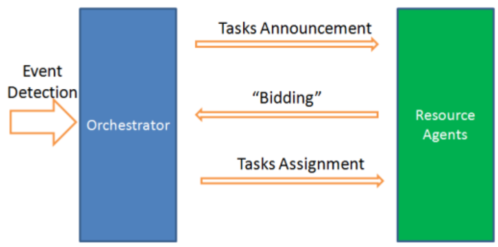

Figure 3: Task Bidding and Allocation Protocol

The protocol comprises three phases:

Phase I: Task announcement. Here, the orchestrator broadcasts tasks with the earliest deadlines (i.e. most urgent tasks) to the agents. Each task will be announced to a subset of agents, based on geographical proximity. Thus, unless there are abundant resources, only the most urgent task will be attended in order to minimize number of failed tasks due to lack of resources. Tasks will eventually become urgent as time elapses and will be assigned at more proper time when their priority is high or when resources are available.

Phase II: Bidding. Each agent will decide whether they want to accept a task. They have to respond within a given time window after the tasks have been broadcasted. If they are willing to accept a task, they will have to specify the estimated time at which they start to perform the task (obviously based on their knowledge of completion time of the tasks on hand and the travelling time to this task). We assume the agents to be cooperative, so agents have no incentives to report false information. Agents can bid for multiple tasks and need not worry about duplication. It is the orchestrator's responsibility to ensure proper task allocation. For example, one agent cannot be assigned to two tasks at the same time; however, it is possible that one agent can be assigned to multiple tasks where one task can be finished first, and the next task is performed at a later time by the same agent.

Phase III: Task assignment. After receiving the bids from agents for each task, the orchestrator will perform solve an optimization problem (see below) based on the success rate (expected likelihood that the task will be completed in time) and number of victims that can be rescued. Tasks will then be assigned to agents based on the solution to this problem.

The three-phase coordination protocol will be performed periodically. We assume that the status of each agent will be automatically updated into the system as tasks are completed. In our experiments, we benchmark the performance under this coordination protocol against a manual myopic scheme in terms of number of victims saved and resource utilization.

B. Optimization Model

The orchestrator produces and assigns tasks based on the following optimization model, which is a stylised single-period stochastic assignment model.

The inputs are:

n: Number of tasks, and $i = 1 \ldots n$

m: Number of agents, and $j = 1 \ldots m$

q_i: Severity of task i (proxy for task quality)

d_i: Deadline for task i

t_{ij}: (Stochastic) Time duration needed to finish task i by agent j

s_{ij}: Estimated start time for task i defined by agent j

Based on the inputs, we can compute the following:

p_{ij}: (Stochastic) utility of task i if assigned to agent j

$prob_{ij}$: Probability that task i is finished before its deadline if assigned to agent j.

The decision variables are:

$X_{ij} = 1$ if task i is assigned to agent j, 0 otherwise.

In this model, we maximize the total utility of performing all tasks for the targeted period, as indicated by the objective function. It takes both number of victims and the likelihood of successfully rescuing them into consideration. Constraints 1 and 2 specify that one agent can be assigned to at most one task at a time, and each task should be performed by only a single agent. Constraint 3 defines the utility of a task i if it is performed by agent j, taking into consideration both the probability of successfully completing the task as well as the number of victims that can be saved. Constraint 4 defines the probability of the actual duration of the task being no longer than the allowed time horizon, which is from starting time until its deadline. In addition, we assume that victims will survive if a task is completed successfully; otherwise no victim can survive.

$$\textbf{Max} \ \sum_{ij} \boldsymbol{p_{ij} * X_{ij}}$$

$$\text{s.t.} \quad \sum_i X_{ij} \le 1, \text{ for all } j = 1,\ldots,m \qquad (1)$$

$$\sum_j X_{ij} \le 1, \text{ for all } i = 1,\ldots,n \qquad (2)$$

$$p_{ij} = prob_{ij} * q_i \qquad (3)$$

$$prob_{ij} = Probability(t_{ij} \le d_i - s_{ij}) \qquad (4)$$

V. Simulation Results

For benchmarking purpose, we compare with a greedy heuristic where all tasks are sorted according to the number of victims, and whichever available agent will be assigned to the task. Our experiments are set up according to the following input parameters:

1) Number of victims of each task: Uniformly distributed between 1 and 50;
2) Estimated duration: Normal distribution with mean 80 and standard deviation of 20 minutes;
3) Actual duration: Normally distributed with mean equal to estimated duration and standard deviation (sd) of 0, 10, and 20 minutes in respective experimental sets;
4) Number of tasks $n = 100$;
5) Resource Availability: 100%, 80%, 60% and 40% in respective experimental sets, which corresponds to $m = 100$, 80, 60 and 40 agents.

Table 1 presents the results after running the optimization model on different experimental sets. Our results shows that although the number of tasks that can be finished successfully decreases as the scarcity of resources increases, the number of victims saved remains at a relatively high level. For example, with 40% resources availability, the number of successful tasks is 39; however, the average percentage of victims saved stays high at around 60%, which is nearly twice the average percentage of the myopic scheme.

VI. Conclusion

There are a number of limitations which could be improved in future. 1) Our optimization model is based on a single period and single resource tasks where each agent is assigned to at most one task during planning; 2) the temporal relationships between tasks are not handled; 3) it is possible to assign multiple teams to a single task so that the task can be completed earlier.

		100%			80%		
		sd=0	sd=10	sd=20	sd=0	sd=10	sd=20
Greedy Approach	Average Coverage[1] (%)	58.89	56.27	56.27	55.20	53.73	52.49
	Average # successful tasks	60	60	60	49	47	45
Coordinated Approach	Average Coverage (%)	96.31	94.67	90.42	93.30	91.78	87.34
	Average # successful tasks	96	95	91	80	77	74
		60%			40%		
		sd=0	sd=10	sd=20	sd=0	sd=10	sd=20
Greedy Approach	Average Coverage (%)	49.26	47.87	47.78	37.53	37.05	36.59
	Average # successful tasks	35	35	35	24	23	23
Coordinated Approach	Average Coverage (%)	83.14	81.06	77.33	63.47	61.69	59.30
	Average # successful tasks	60	59	56	40	39	38

Table 1: Comparison of Optimisation and Simulation Results

While there are clear limitations to our proposed optimization model, our research provides a bidding framework for logistics orchestration in humanitarian operations, and good insights into the potential of applying the concept of orchestration among different resource teams. This serves as a foundation for more realistic models in the future.

There are possible extensions at the system level - for example, implementing portals for exploration teams and resource agents, so that the related resource agents also can "bid" the open tasks through the portal and update their statuses. In addition, the orchestration application could be extended with self-registration of resource agents and exploration teams.

ACKNOWLEDGEMENT

We thank Baitao Zhou for pointing us to relevant literature and technical assistance with simulation tool.

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[1] Average coverage is defined as the percentage of victims saved out of all the victims found/reported.