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A SIMULATION-OPTIMIZATION APPROACH TO DESIGN A RESILIENT FOOD SUPPLY NETWORK FOR NATURAL DISASTER RESPONSES IN WEST JAVA

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ABSTRACT

We present the development of a simulation-optimization approach to build a resilient food supply network for natural disaster responses in West Java, Indonesia. The objective of the model is to support disaster preparedness and response decisions, such as warehouse locations, replenishment policies and response allocations. Our approach is designed to understand the trade-off among the two criteria of effectiveness, i. e. fulfilment of the demands, and of efficiency, i. e. response time, storage and operational costs. It will allow both the evaluation of the current system, which is managed separately for different food items, and the investigation of the coordinated use of shared resources.

1 INTRODUCTION

West Java province has the highest multi-disaster risk in Indonesia and it contributes significantly to the economy of the country, in terms of outputs and as the center of rice production. Hence, natural disasters may impact not only the local people but also at the national level. Depending on the severity, a disaster strike may force a local population to become refugees who require urgent help. In this work, we focus on the storage and distribution of relief food items, where the first fourteen days of the strike are considered by the Indonesian regulation as the emergency period for which the items have to be delivered immediately. In this work, we focus on four types of natural disasters: landslides, flood, earthquake and volcano eruption. These disasters are frequent but mostly of small or medium scale (e. g. around three disasters daily in 2017); however, the risk of large-scale disaster cannot be ruled out due to the existence of two major fault lines. In our current study, we will focus on the small scale but frequent disasters, and addressing larger scale disasters will be considered later in this project.

The preparation and delivery of the relief responses require the coordination of several agencies. Particularly for rice, the most popular staple food in the country, the storage and distribution is handled by the state logistics agency which also has other responsibilities such as market intervention for rice price or social welfare. Thus the agency has 45 warehouses of large capacities, while some other food items are supplied by other agencies under the coordination of the regional agency for disaster countermeasure.

2 SIMULATION-OPTIMIZATION APPROACH

At the top level of our modelling, we use simulation optimization to determine global parameters such as the optimal selection of warehouses and the choice of policies to use for operational decisions during the planning horizon. Our goal is to understand the trade-off between the criteria of effectiveness, i. e. fulfilment of the demands, and of efficiency, i. e. response time, storage and operational costs. Aside from the multi-objective aspect, our problem is also multi-periodic, stochastic and dynamic at the same time, and the effective use of simulation-optimization techniques, such as OCBA (Chen and Lee 2010), is essential. As far as we know, the closest work related to ours is (Tavana et al. 2018), however the proposed model in that paper considers a fully integrated inventory-routing decision model.

We use Monte-Carlo simulation to generate disaster scenarios, where a scenario defines a set of events that will occur during the planning horizon. This simulation will serve as a proof of concept for an agent-based model that incorporates the complexities of interactions between aid organisations and refugees. Information regarding the demand locations and quantities as well as the characteristics of the connections between the warehouses to these locations is then fed into the lower level components that carry out day-by-day operations. These components, which represent the possible activities of the agencies involved, are separated into two categories: inventory management and response allocation/relief dispatching. The function of each component is associated with solving a well-defined deterministic optimisation problem.

Since the policies and parameters for the warehouses are already fixed at the upper level, and the demand and consumption are available daily during the time horizon from the relief dispatching components, the problem to be solved for inventory management at the warehouses is generally straightforward. On the other hand, the optimisation problem for relief dispatching can be modelled as a mixed integer program. Three objectives have to be minimized in their prioritized order, and they are respectively: the (un)fulfilment of the demands (1), the response time (2), and the cost of deployment and operation (3):

$$\min \sum_{m,i} y_{mi}, \text{where } d(m,i) - \sum_{k,v} \omega(i) f_{kmvi} \leq y_{mi} \ \ \forall m, \forall i \tag{1}$$

$$\min \sum_{m} \hat{r}_m, \text{where } r_{mv} \leq \hat{r}_m \ \ \forall m, \forall v \tag{2}$$

$$\min \sum_{k,m,v} \big(e(k,v)\hat{z}_{kmv} + \tilde{L}(k,m,v)c(v)z_{kmv}\big) \tag{3}$$

Here the decision variables $f_{kmvi} \in \mathbb{N}$ tell the quantity of item i to be delivered from warehouse k to affected location m by vehicle v. The other variables, whose indices are subscripted, are deduced from f_{kmvi} and the problem parameters by setting the appropriate constraints, e. g. r_{mv} indicates the arrival time of vehicle v in its last trip at location m. The problem parameters specific for the day are written in function forms (i. e. using parentheses), e. g. $d(m,i)$ is the demand of item i at location m. We have identified three constraints for this problem, whose formulations are omitted due to the space limit: the availability of items at warehouse and vehicle capacities, the operational time limit of each vehicle, and finally that a vehicle is assigned one mission per day but multiple round trips are allowed. Our formulations are indexed by the item, thus allow both the modelling of the current system as well as investigating the possible use of shared resources.

3 CONCLUSIONS

We have proposed a simulation-optimization approach that has the ability to capture and model the function of the food supply network for natural disaster responses in West Java. The next step in our research is to test the proposed model on the real historical data of the region, to provide us with insights into our modelling and solution approach, and into the performance of the system currently in operation.

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