Vehicle Route Planning for Disaster Relief

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***Abstract*—Large-scale disasters may cause extensive damage to transportation, and infrastructures facilities, and make them un- available for emergency relief operations.A smart route planning system helps the government and disaster relief organizations prepare for and manage such situations and carry out relief efforts effectively. The aim is to build a system that can be integrated with existing systems implemented by local agencies and non-governmental organizations (NGOs) to deliver disaster relief supplies efficiently by solving vehicle routing problem (VRP) to help people in distress. The system aims to reduce the associated computational complexity and generate near-optimal solutions.**

***Index Terms*—Disasters, Vehicle Route Planning, Computa- tional Complexity**

I. INTRODUCTION

Vehicle routing problem refers to the determination of the shortest cyclic path through multiple points, for a fleet of vehicles passing through each point only one single time. In case of a single vehicle the problem is reduced to the traveling salesperson problem. When disasters occur, vehicles are used to carry supplies in disaster stricken areas to help victims. A system can be integrated with existing processes to fulfill these objectives whose primary users will be the local agencies and NGOs that manage the distribution of relief supplies in disaster-stricken areas.

II. LITERATURE SURVEY

This section presents the various advantages and limitations of different techniques that have been developed and used extensively in the literature.

A. *2-opt heuristic algorithm*

The 2-Opt heuristic is an improved method for the Trav- elling Salesman Problem. It starts with a tour in an arbitrary direction and then repeatedly replaces a pair of edges of the tour by two other edges, till it yields a shorter tour. This is used to minimize the cost of each route in the vehicle.

B. *Distance Based Route Find (DBRF)*

It focuses on resolving the issue using a simple solution for Traveling Salesperson Problem that is TSP. A vehicle should travel to an upcoming destination that is closest to the current destination so that traveled distance can be minimized. The process continues until all the area demands are fulfilled.

C. *Priority-Based Route Find (PBRF)*

Nodes are assigned priority, which further varies according to the magnitude of the disaster and need in the area. Therefore the serving depends on the precedence of the nodes. Thus high-priority destinations are served first and then further destinations with low priority.

D. *Hybrid Route Find (HRF)*

An improvement to both DBRF and PBRF is required to associate locations and priority efficiently. Thus, HRF serves both purposes. Vehicles need to route all areas with high-priority which is given by PBRF. Once done, the other locations are routed according to the DBRF approach.

E. *Differential evolution algorithm*

The exponential ranking technique is used to make indi- viduals that consist of exponential probability to enter into the mutation stage. It will enhance the exploitation capacity. The exploration ability of the algorithm is maintained.

F. *Constrained Clustering*

Constrained clustering is used for clustering data in which constraints are generated by including domain knowledge. The constraints are demonstrated in the form of pairwise statements. This shows that the locations should be situated in the same cluster.

G. *Multi-Container Web Application*

The applications are deployed on multiple container envi- ronments, and then the work done by all the containers are merged. This architecture is available using the docker swarm tool which is used for scheduling and orchestrating docker containers.

III. EXISTING SYSTEM ARCHITECTURE

Each step in the above diagram is dependent on the suc- cessful execution of the previous step, so even if one of the step causes failure, it will halt the entire process. In the above architecture, node locations, distances, and capacity of the vehicle are taken into consideration. The Constrained Vehicle Routing Problem (CVRP) solver algorithm is applied directly to the entire topology or network of nodes at once. The CVRP

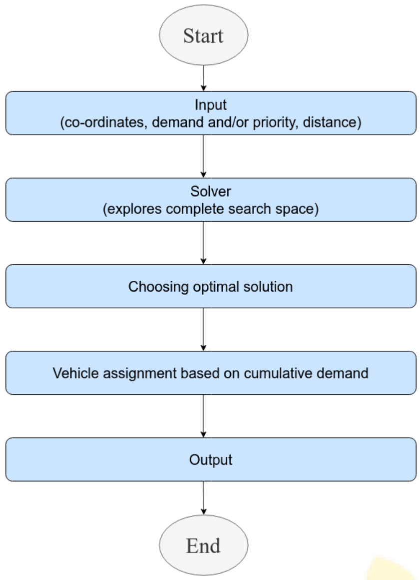

Fig. 1. Existing System Architecture.

is categorized under NP-hard problems. Thus the time taken to solve the problem employing the current architecture increases exponentially because the number of locations in the input increases.

IV. PROPOSED SYSTEM ARCHITECTURE

The strengths and weaknesses of existing systems have been discussed. Researchers have combined various techniques to develop hybrid domain systems that retain the advantages and eliminate disadvantages.

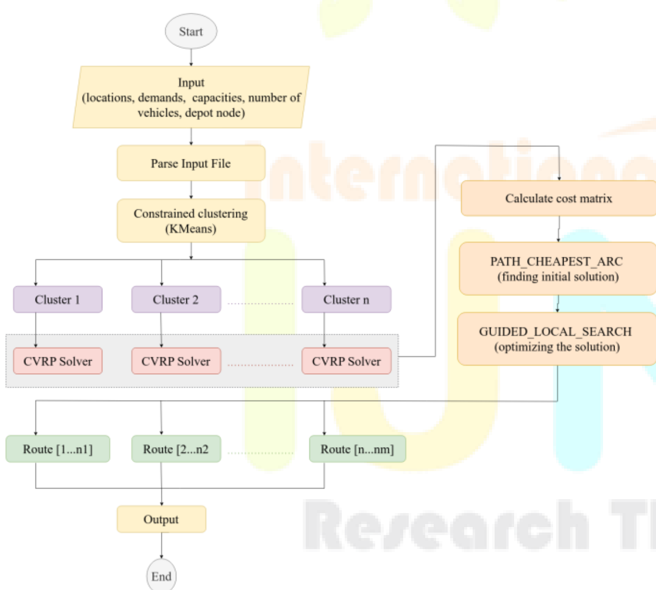

Fig. 2. Proposed System Architecture.

V. IMPLEMENTATION DETAILS

The system will be deployed using containerized archi- tecture on the cloud to make it scalable and secure. Con- strained K-Means Clustering, Path Cheapest Arc Algorithm, Guided Local Search Algorithm will be used to generate and optimize the found routes. Usage of search algorithms with meta-heuristics optimization will be employed for reaching the solution faster. Container orchestration will be used to dynamically scale the system as per need and for setting up virtual networks that will isolate the processes at network level. The system will boost the speed of computation by distributing the sub tasks across nodes.

VI. ALGORITHMS AND TECHNIQUES

A. *Clustering using constraints*

The CVRP is categorized under NP-hard problems. It is used to resolve compact problems only. Heuristic algorithms that are further clustering based, are employed to resolve this issue for large-scale occurrences. The Constrained Clustering regarding the CVRP (CC-CVRP) is constructed using K- Means. It is used where locations are organized as clusters. Each generated cluster is allocated a subset of vehicles which is based on their total demands.

The CVRP generated has the following attributes: A cluster should have at least one location excluding the depot's lo- cation; Each location can belong to one cluster only; The assigned vehicles should be able to serve all locations in the cluster and accordingly the clusters are determined. CVRP is solved for the capacitated vehicles to determine the optimal cost routes for all points in each cluster. Our CC- CVRP approach is led by determining clusters. The first set of fulfilled clusters are determined by each vehicle when clusters are beforehand provided. Once done, the optimal sequence for visiting the customers is determined.

We implement the Constrained Clustering Algorithm using this obtained data. We solve the clustered CVRP by using a heuristic solver. Vehicles are assigned to clusters that may contain more than one location. We determine an optimal route for each vehicle serving these customers.

B. *Virtual Networks*

Virtual networking helps for the communication to happen among multiple computers, virtual machines etc, across vari- ous distributed locations. Virtual networking helps connect computers and servers via the Internet. The system's frontend, backend, and ML Model all are in separate containers running in isolation. Network layer isolation is handled by virtual networks. Containers can interact with other containers present on the same virtual network by configuring their ports. To reduce the surface of a network attack, containers are often isolated across virtual networks. Our system consist of three virtual networks (VN):

1) Frontend (React): VN1
2) Backend (NodeJS) + Database(MongoDB) : VN2
3) Backend (NodeJS) + ML Model (Flask) : VN3

C. *Load Balancing*

A load balancer accepts incoming traffic from the client's side and routes requests to the registered targets. The load balancer also monitors the nodes and ensures that it routes traffic only to nodes which are alive. Traffic routing to the node that is not responding to requests is stopped, declaring it dead. Routing traffic is then resumed to that node only after it detects the node has become active again. Crashed or terminated processes are restarted on different nodes and the same changes are reflected in the load balancer's configuration dynamically.

D. Path Cheapest Arc Algorithm

We use the first solution strategy as a method to find an initial solution for which we employ the Path Cheapest Arc algorithm. It starts from a "start" node and connects it to the node producing the cheapest route segment. The algorithm then extends the route. It iterates on the last node that is added to the route. Thus it grows the route by extending it.

E. Guided Local Search

The main focus of Guided Local Search is on the exploita- tion of the information related to search to guide local search heuristics within search domain. Solution features are defined for a given problem to differentiate among solutions with unique characteristics, so that similar areas around the local optima can be prevented. We aim to penalize features that have high costs. It uses an augmented cost function. Thus the local search algorithm is led outside of the local minimum, by penalizing features that are available in the local minimum. It becomes high-cost as compared to the surrounding search space. Here, the said features are not available.

F. Haversine formula

The law of haversines relates angles and sides of spherical triangles. It is a broad formula in spherical trigonometry which is significant in navigation. For calculating the distances on a sphere, the Haversine formula provides one of the most accurate results. The equations below are translated to include the latitude and the longitude coordinates, where φ, λ, R are the latitude, longitude and earth's radius (approximately 6,371km) respectively.

$$a = sin^2(\Delta\varphi/2) + cos(\varphi 1) \times cos(\varphi 2) \times sin^2(\Delta\lambda/2) \quad c = 2 \times asin(min(1, \sqrt{a}))$$

$$d = R \times c$$

G. K-Means Constrained Clustering

K-means clustering implementation specifies the maximum and minimum size for each cluster. These values can be calculated based on the processing power and memory limit of a single machine. Modifications in the cluster assigning step by preparing a Minimum Cost Flow (MCF) linear network optimization problem. Cost-scaling push-relabel algorithm is then used for solving using Google's Operations Research tools's SimpleMinCostFlow implementation.

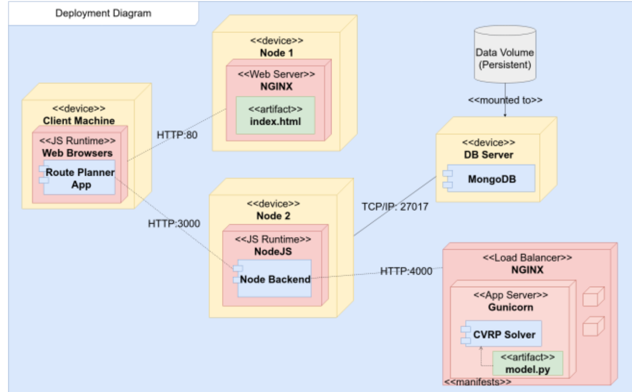

Fig. 3. Deployment Diagram

VII. DEPLOYMENT

The 3D cubes in the diagram represent a device or different execution environments. The rectangles in blue represent the different components within the system. These components are manifested using artifacts represented using green colored rectangles. Artifacts can be thought of as source files. The system will be deployed on multiple nodes, consisting of:

1) The NGINX web server, for serving our frontend.
2) The NodeJS backend as an interface between the fron- tend and the DB.
3) The DB server is mounted with a persistent data volume.
4) The Solver runs on a Gunicorn app server over multiple machines.

VIII. DATASET USED

node	latitude	longitude	demand	priority
1	25.991615	91.25782	0	2
2	26.628309	92.122353	7	2
3	24.864511	92.564377	2	2
4	27.409889	95.627396	9	2
5	26.419544	92.342041	10	2
6	26.730125	91.378769	3	2
7	27.832275	95.221451	9	2
8	26.397966	92.304909	3	2
9	24.755955	92.830292	10	2
10	26.456781	93.938789	5	2

name	dimension	max_demand	total_demand	total_trucks_capacity
PRB-n20-k6	20	10	105	240

capacity	no_of_trucks	depot_node	optimal_value
40	6	1	

Fig. 4. Sample Dataset

Datasets used in the system were gathered from http://vrp.galgos.inf.puc-rio.br/index.php/en/ website. Addi- tional datasets were synthetically generated with the necessary features. The figure shows the sample of one of the many datasets used from the given sources with an instance repre- senting the name of the dataset in which *n* is regarded as the total amount of nodes and *k* is regarded as the total amount of vehicles available for traveling through the generated route to deliver relief supplies. The available '.vrp' files from the above website were pre-processed and converted to spreadsheets for easier parsing.

IX. RESULT AND ANALYSIS

The actual locations are plotted on a map with the help of a mapping service (Google Maps) and other basic information pertaining to the solution is shown over it in Figure 5.

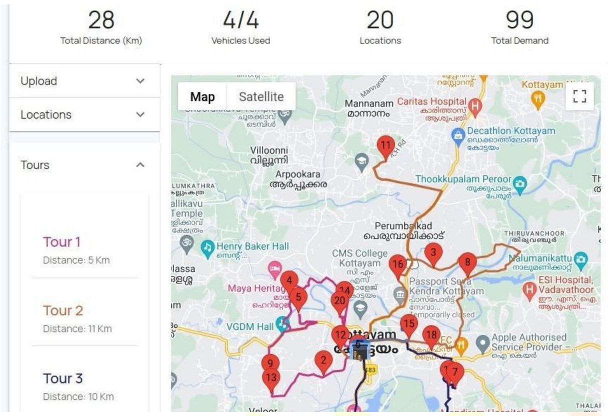

Fig. 5. Routing

The comparison between the total distance traveled by all vehicles over *x* number of nodes is shown in Figure 6. The chart shows that the overall distance is slightly less for serving the nodes in the proposed system as the number of nodes increase for a constant timeout during exploration of search space.

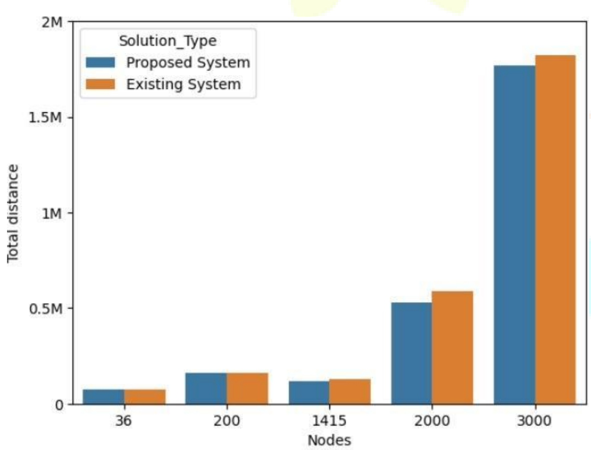

Fig. 6. Distance vs Nodes

The line chart in Figure 7 shows the most deviation from the existing behavior as an increase in number of nodes leads to steep rise in computation time while for the proposed architecture the time increases with a relatively gentle slope.

The chart in Figure 8 shows that the number of vehicles used are slightly less for serving the nodes as the number of nodes increase; this is due to the usage of vehicles to its full capacity before starting out from the depot and reducing the number of partially loaded vehicles.

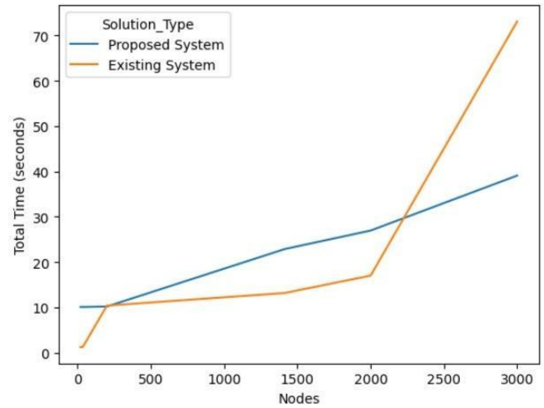

Fig. 7. Time vs Nodes

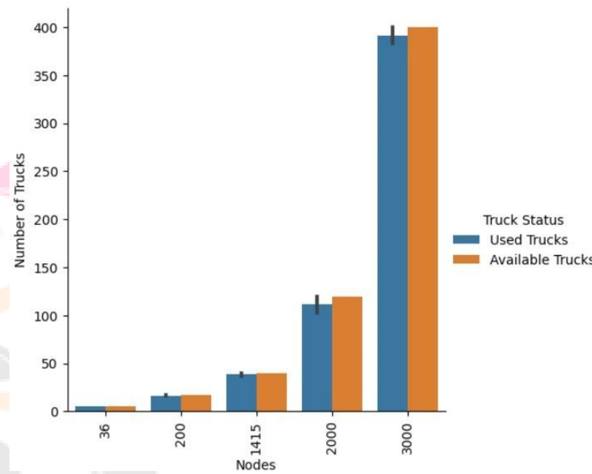

Fig. 8. Trucks vs Nodes

X. CONCLUSION

A model for emergency logistics planning for relief oper- ations is developed in this project. Model outputs consist of vehicle route planning for sending relief materials to disaster- stricken areas/relief camps. The proposed model uses cluster- ing approach with constraints like the demand of locations, distance, and capacity of vehicles to divide the location nodes into several clusters. This allows us to apply the algorithm for CVRP at different clusters simultaneously and reduce the problem size and time complexity. The results indicate that at the expense of a slightly less feasible route we are guaranteed to find a solution that can be computed in parallel and require less computing resources.

However, further research should be carried out for multi- depot and time window constraints for CVRP. The risk associated with certain routes can also be considered in the domain knowledge which can help in better decision making.

XI. ACKNOWLEDGEMENT

We would like to express our gratitude to Prof. Suresh Babu, our project guide who helped us in applying the knowledge

that we acquired during the semester and learned new con- cepts.
We would like to express our special thanks to Prof. Sharvari Govilkar the H.O.D of our Computer Engineering department who gave us the scope to undertake this project through which we could learn various new concepts and their applications.
We are also thankful to our project coordinator Prof. Payel Thakur along with other faculties for their encouragement and support.
Finally, we would like to express our gratitude to Principal Dr. Sandeep Joshi who gave us the opportunity and facilities to conduct this project.

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