LaCAVR: Load and Constraints Aware Vehicle Rerouting

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***Abstract*—We present a prototype system for effective management of a delivery fleet in the settings in which the traffic abnormalities may necessitate rerouting of (some of) the trucks. Unforeseen congestions (e.g., due to accidents) may affect the average speed along road segments that were used to calculate the routes of a particular truck. Complementary to the traditional (re)routing approaches where the main objective is to find the new shortest route to the same destination but under the changed traffic circumstances, we incorporate two additional constraints. Namely, we aim at striking a balance between minimizing the additional expenses due to drivers overtime pay and maximizing the delivery of the goods still available on the truck's load, possibly by changing the original destinations. The project is developed with an actual industry partner with main business of managing supplies for office pantries, kitchens and cafés.**

***Index Terms*—Vehicle Rerouting, Delivery Constraints, Internet of Things,**

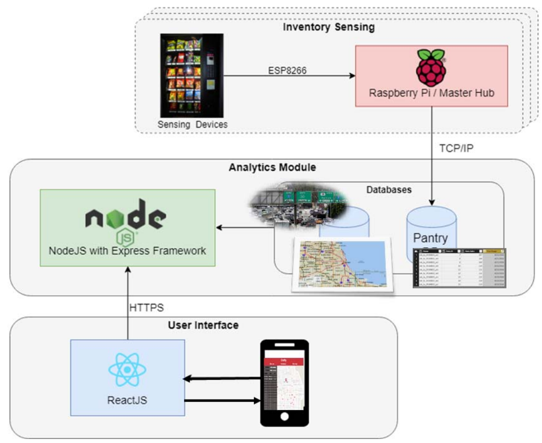

Figure 1: Main Functional Units

I. Introduction

One of the most extensively studied problems in Operations Research (OR) since the 1950s is the Vehicle Routing Problem (VRP) [1]. In a nutshell – given a depot (D); a set of customers' sites (with locations and demands) $S = \{(s_1, d_1), \ldots, (s_k, d_k)\}$; and a set/fleet of trucks $T_r\{\tau_1, \ldots, \tau_m\}$ $(m < k)$ with a limited cargo carrying capacity – the VPR problem seeks to assign least-cost routes to the trucks such that the demands of the customers are met, and additional constraints are satisfied. For example, additional constraints include: (i) capacity restrictions – i.e., the sum of weights in demands along the sites of τ_i's route may not exceed the capacity of τ_i; (ii) travel time (or distance) bounds; (iii) time windows – i.e., deliveries at particular location may be done within particular time-interval only; etc. [1], [2].

Motivated by an actual application addressing the supply management for snacks and beverages at the levels of office pantries, cafés and events (Crafty Inc. – https://craftydelivers.com), we took a first step towards addressing a novel variant of the VRP problem, described as follows. In practice, in addition to incorporating the other constraints (e.g., cargo carrying capacity), when planning the daily trips for the delivery trucks an important parameter is the distance between the delivery points. More often than not the travel-time distance is used in planning, instead of using only the traditional Euclidean distance [3] – since the parameters characterizing the segments of a road network (e.g., traffic density, average speed, etc.) may vary within different periods of a day. While time-dependent variants of the shortest path [4] can be used to augment the traditional VRP heuristics such as Clarke & Wright capacitance aware VRP algorithm [5] (or various extensions [2]) – one specific variant of the problem that has not been addressed is: *How to adjust the routes in the event of traffic abnormalities* (i.e., abrupt changes of the values of the parameters describing the segments along the road network, used for calculating the routes) *while minimizing the penalties*. Specifically, we consider two types of constraints that specify the penalties: (C1) overtime payment for the drivers; and (C2) quantity of goods not delivered – i.e., returned to the warehouse.

Our global aim was to develop an end-to-end solution for demand/supply management based on the Internet of Things (IoT) paradigm. A high-level description of the architecture of the systemis presented in Figure 1, with a note that a more detailed description and the source code(s) are available at http://http://sdmay19-29.sd.ece.iastate.edu/.

The main modules consist of:
(i) sensing devices which estimate the number of available items based on the weight in the corresponding storage units (e.g., a vending machine or a cupboard) and transmit them to

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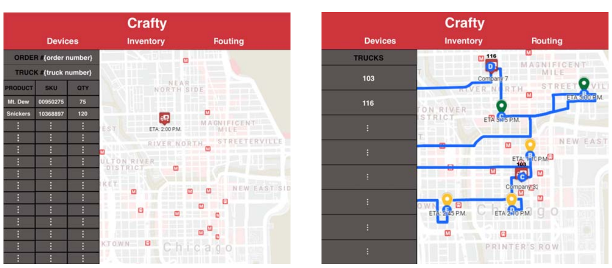
the database in the analytics server;
(ii) analytics server which consists of: (a) a database server that is updated with the status of each item for the respective customers; (b) routes and trajectories server which, given the state of the demands and the location of the customers, plans the load for the trucks and their routes from a given warehouse; (iii) mobile apps that provide: (a) a view of the current status (i.e., demands) for a particular customer; (b) a view of the status of the scheduled deliveries; (c) notifications and navigation for the drivers.

The state of each truck is specified with the values of two additional variables: (1) Current location (obtained via on-board GPS device); and (2) Current payload, updated at each delivery location by subtracting the requested amount of products for the respective customer from the previous payload. As mentioned, in this work we incorporate the updates of the parameters describing the road networks (e.g., average speed) and, based on those updates and the current location of a given truck, a new route may be generated, subject to a weighted combination of the constraints C1 and C2.

II. Interaction and Demonstration

The main two categories of interfaces through which users can interact with the delivery status are illustrated in Figures 2(a) and 2(b). The left portion shows the details of a an order (items and quantity) for a particular customer, along with the location of the delivery truck and ETA. The right portion illustrates the interface in which the trajectories and the positions of individual trucks along them are displayed.



(a) Items and ETA (b) Routes

Figure 2: Delivery Status and Routing Interfaces

The demo will illustrate the use and interplay of all the main system architecture components shown in Figure 1, as well as the constraint rerouting heuristics. Specifically, it will consist of the following main three portions, that will be re-started within approximately 10-minute intervals:

Part I *Sensing and Inventory Generation* – This part of the demo will illustrate the use of the custom-made sensing devices that were developed as part of the overall project. The participants will have the opportunity to:

- Physically remove different items (a Snickers bar and a can of soda).
- See how the inventory database in the Analytics Module was updated via the hub (Raspberry Pi) for the corresponding customer/site.
- Additionally, if the supply level of a particular item has dropped below a certain pre-defined threshold, an order for that item is created (based on a pre-defined policy).

Part II *Trajectories Planning* – Once the orders have been completed for a given day, and the collection (i.e., fleet) of available trucks with corresponding specifications for the cargo capacity has been determined, the route generator in the analytics module will execute the Clarke & Wright heuristics and generate the trajectories for the trucks, to start on the next business day. For this part of the demonstration, we rely on SMARTS (Scalable Microscopic Adaptive Road Traffic Simulator – https://projects.eng.unimelb.edu.au/smarts/) to generate traffic patterns and vary them within different times of the day and along different road segments. We will illustrate a scenario based on the streets of the City of Chicago via OpenStreetMap (http://www.openstreetmap.org) and corresponding to 12 different locations. To illustrate the tracking features, we will use the (*timestamp, latitude, longitude*) data for the trucks obtained from the output files/traces generated by the STREAMS. The participants will have the opportunity to experience the execution of SMART, and the interfaces for:

- Viewing the current state of a given truck (its location, payload, and ETA to the next delivery location).
- Viewing the trajectory of a given truck and its current location on it.

Part III *Rerouting* – This part of the demo will also utilize the features of SMARTS – notably, its capability to generate a traffic congestion along a particular road segment. The crucial steps following such an event are:

1) Determine the trajectories that are affected by the traffic abnormality (and the corresponding trucks).
2) Determine the current payload of the affected trucks.
3) Based on the constraints C1 and C2, and on the status of the demands of the customers in the database who were not scheduled for a delivery on that date, determine the new trajectory of the affected truck.

The participants will have the opportunity to experience the updates of the interfaces from Part II of the demo. In addition, we will discuss our ongoing work on improving the overall efficiency of the rerouting process by incorporating pruning techniques to eliminate the sites that are beyond certain distance threshold with respect to the constraints.

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