SMART LAUNDRYNAV: A WEB AND MOBILE APP FOR OPTIMIZING STATIC-DYNAMIC ROUTES USING A GENETIC ALGORITHM IN LAUNDRY HUB LOGISTICS

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ABSTRACT: *This study explores the significance of route optimization in laundry hub logistics, utilizing a Laundry Management System (LMS) that offers pick-up and drop-off services to its growing customer base. The lack of a strategic route plan for these services previously resulted in unnecessary expenses for vehicle usage and additional manpower, subsequently escalating operational costs. To address this issue, an intelligent route optimization for web and mobile applications was developed incorporating a static drop-off and dynamic pick-up route plan using a Genetic Algorithm (GA), integrated into the existing LMS. The implementation of a dynamic route plan for pickup while a vehicle is enroute within the Estimated Delivery Time (EDT) further improved client demand management and resulted in reduced operational costs and optimized route navigation. This route optimization considered factors such as distance traveled, vehicle capacity, and time window. It is recommended that future research incorporates more factors to consider such as traffic conditions, rerouting due to road works, and other road-related factors that could influence the proposed route.*

Keywords: Route Optimization, Genetic Algorithm, Vehicle Routing Problem (VRP), Dynamic Route Plan

1. INTRODUCTION

Optimizing routes can significantly enhance efficiency for businesses like Dirtbag, where logistics are a crucial component of operations. Based in Cagayan de Oro City, Dirt-bag is a laundry service that adapted to the constraints imposed by the Covid-19 pandemic by developing an online laundry management system. This system offers convenient pick-up and drop-off services for customers within the city.

However, as the client base expanded, so did the need for cost-effective logistic planning to maintain a balance between customer satisfaction and business productivity. The lack of an effective route plan for both pick-up and drop-off services resulted in multiple vehicle movements, leading to inflated operational costs.

This paper proposes a solution to this issue by integrating a route optimization module into the laundry logistics system. This addresses the Drop-off and Pick-up Problem (DPP), akin to the Vehicle Routing Problem with Pick-up and Delivery (VRP-PD). The goal here is to devise an optimal route that minimizes travel costs, which include fuel expenditure, distance covered, and time taken for a vehicle to depart from a laundry hub[1-3], visit each client once for drop-off, and pick-up laundry on the return trip.

The study extends this optimization to account for both route and vehicle capacity during drop-off and pick-up within a specific timeframe. This approach aims to enhance work efficiency, boost productivity, and improve customer service.

The system devises an optimized route plan considering two aspects: a static route plan for drop-offs and a dynamic one for pickups. For drop-offs, a static route plan guides the vehicle from the hub to each client, with an estimated drop-off time (EDT) calculated from departure until the final client.

For pickups, the route plan is dynamic yet constrained by EDT and vehicle capacity. It continually updates when a new pickup request is received within the EDT range and vehicle capacity while the vehicle is enroute.

The system employs a hybrid static and dynamic routing solution to provide cost-effective, time-saving, and fuel-efficient logistics operations. The Genetic Algorithm (GA) is used as the route optimization solution based on several literature reviews[4-7].

This route optimization system is integrated into Dirtbag's existing laundry logistics operations, enhancing efficiency and effectiveness by reducing operational costs. It also opens up opportunities to cater to increasing client demands without compromising service quality.

The primary aim of this study is to utilize GA to develop an optimized route plan for drop-off and pick-up services and implement it via mobile and web applications integrated into Dirtbag's existing Laundry Management System.

System Framework

Figure 1 illustrates the conceptual framework detailing the amalgamation of Dirt Bag's pre-existing Laundry Management System (LMS) with the Route Optimization System. Essential data, encompassing client information and pick-up/drop-off details necessary for constructing a route plan, will be derived from the established LMS. Subsequently, the Route Optimization System employs a genetic algorithm to generate an optimized route plan that encompasses both drop-off and pickup routes. The resulting route plan is then communicated to the designated driver via a mobile application and associated with the assigned cluster vehicle, serving as a guiding reference during laundry drop-off and pick-up operations.

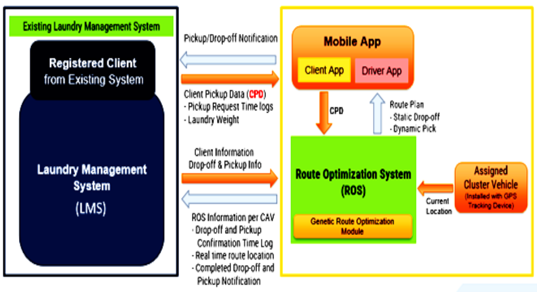

Figure 1: Integration of Route Optimization System Conceptual Framework

2. METHODOLOGY

Phase I: System Design and Development

The integration of the route optimization system was crucial in gathering data, as all routes were derived from the existing LMS. Several tasks were undertaken to thoroughly examine the integration of both systems: (1) Scrutinizing the database design of the LMS to validate data storage and identify essential missing data for the route optimization design. (2) Acquiring a comprehensive understanding of the LMS functionality and behavior, including the existing processes and their interrelationships, to ensure seamless integration of the route optimization system. (3) Recognizing LMS policies and constraints, maintaining system restrictions, and incorporating system policies during the route optimization design.

Figure 2 illustrates the flow of data and the connections among entities within the system. In this system, route optimization identified four external entities: the Client, Laundry Management System, Route Optimization Module, and Cluster Vehicle. The figure depicts the data requirements (inward arrows) and data provision (outward arrows) from each entity as they traverse through the system.

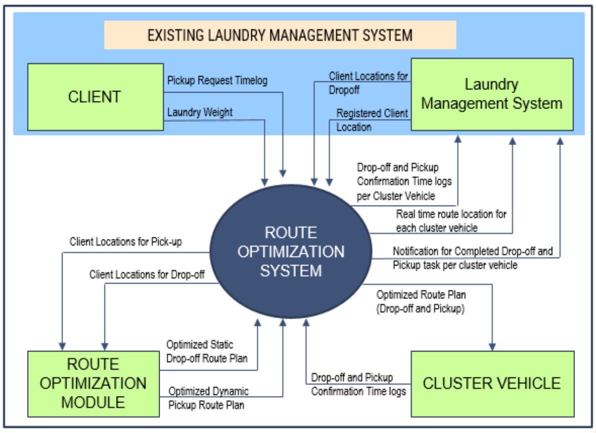

Figure 2: Context Diagram

Figure 3 depicts the architectural design of the system. The client tier outlines the application utilized by system stakeholders, specifically Dirtbag and its Clients. Dirtbag employs both a web application for route management and a mobile application to monitor routes for designated drivers. Clients utilize mobile applications for scheduling laundry appointments. The application tier represents the technology employed in implementing the route optimization system. This includes the integration of various technology applications, such as cloud-based APIs for location tracking, MAP APIs for route plan creation, Genetic Algorithms implemented in Python for generating optimized route plans, and other necessary APIs for data retrieval and processing. A data management server was utilized to store all system data.

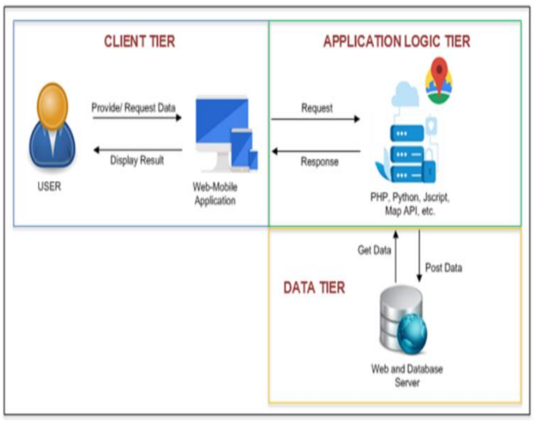

Figure 3: System Architecture Design

The data utilized in this research originated from Dirtbag Laundry Company in Cagayan de Oro City, with location and distance measurements conducted through the Google Maps tool.

The creation of route plans adheres to a one-directional approach, wherein a direct route is established for dropping off clients (from the hub to the last mile drop-off). Simultaneously, a separate direct route is devised for picking up clients (backhaul), commencing from the last mile drop-off client back to the hub. Additionally, for the implementation of dynamic pickup routes (refer to Figure 4), a constraint is imposed within the Estimated Drop-off Time (EDT). The EDT calculation originates from the departure time of the vehicle from the hub and concludes with the estimated travel time from departure to the last mile drop-off location. The route plan assumes that all drop-off items originate from the hub, and all pickup items are returned to the hub.

The Genetic Algorithm (GA) is a search-based optimization approach grounded in Genetics and Natural Selection principles [9, 10]. This method proves valuable for identifying optimal or nearly optimal solutions to combinatorial optimization problems that conventional methods struggle to efficiently solve [11-13]. The algorithm emulates natural selection, mirroring the selection of the fittest individuals for reproduction to produce the next generation's offspring [14]. Each solution is depicted as a chromosome, comprising a sequence of genes that represent a potential problem solution. GAs operate on a population of solutions, manipulating them over multiple iterations referred to as generations. The algorithm progressively identifies better solutions by pairing parent chromosomes to generate offspring or introducing random mutations to previously generated chromosomes.

The GA's structure begins with an initial population, which can be generated randomly or seeded through other heuristics. Parents are selected from this population for mating, and crossover and mutation operators are applied to generate new offspring. These offspring then replace existing individuals in the population, and the process repeats. In this manner, genetic algorithms simulate aspects of human evolution.

The data used in this study came from Dirtbag Laundry Company in Cagayan de Oro City and location and distance data measured by using the Google Maps tool.

A. Defining Constraints: Routes plans are created on one-directional route wherein a straight route for drop-off clients (from hub to last mile drop-off) is created. A separate straight route for pickup clients is also created (backhaul) wherein the route will start at the last mile drop-off client back to the hub. Furthermore, for dynamic pickup route implementation (Figure 6), it is constraint within the Estimated Drop-off Time (EDT). Calculation of EDT is from the start time based on vehicle departure from the hub and end time based on the estimated calculation time travel from departure time to the last mile drop-off location. The route plan also presume that all Drop-off goods come from Hub and all Pickup goods are taken back to Hub.

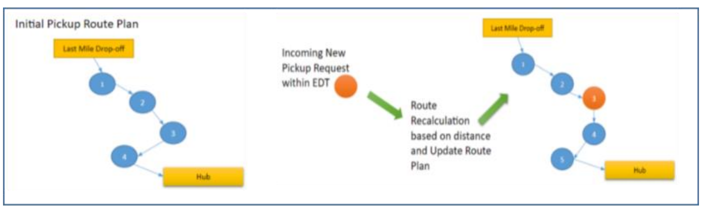

Figure 4: Dynamic Pickup Route Process

Phase II: Web and Mobile Creation

Genetic Algorithm (GA) is a search-based optimization technique based on the principles of Genetics and Natural Selection[9, 10]. This technique is useful for finding the optimal or near optimal solutions for combinatorial optimization problems that traditional methods fail to solve efficiently [11-13]. This algorithm reflects the process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring of the next generation [14]. Each solution is represented by a chromosome, which consists of a sequence of genes that represent a solution to the problem. GAs operate upon a population of solutions, which are manipulated over several iterations, which are called generations.

Web Application Implementation involves a systematic process to ensure the effective development of a robust platform. The initial step is a comprehensive Requirement Analysis where the specific features and functionalities of the web application are identified, and input parameters for the Genetic Algorithm, such as pickup points, drop-off points, vehicle capacity, and time windows, are defined(refer to Figure 5).

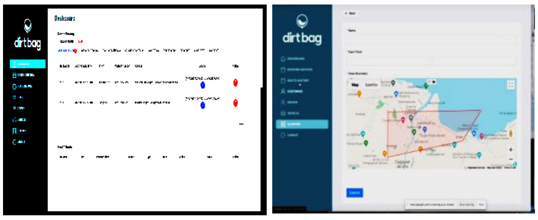

Figure 5 Pickup and Drop off

The subsequent phase, Backend Development, encompasses the creation of a backend capable of managing data storage, retrieval, and processing. Within this phase, the Genetic Algorithm is implemented to optimize routes, involving the development of algorithms for route generation and evolution based on predefined criteria. Following this, API Development is crucial for enabling communication between the frontend and backend. APIs are created to establish endpoints for submitting requests, retrieving optimized routes, and dynamically updating route information. Database Integration is then executed to store and manage data related to laundry orders, route plans, and historical information. It is essential to ensure that the database schema supports efficient storage and retrieval of pertinent data. Moving on, Frontend Development focuses on creating a user-friendly interface for the web application, allowing users to input pickup and drop-off details and implementing a dashboard for displaying route information, optimized

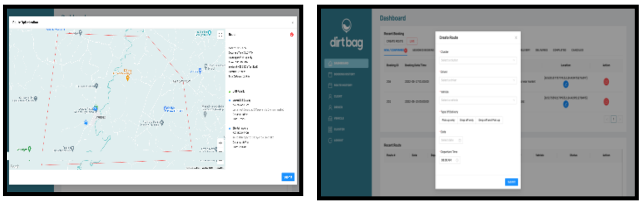

Figure 6 Optimize and Update Route

routes, and updates (Figure 6). The User Authentication step involves securing access to the application by implementing user authentication and defining user roles and permissions to control access to various features[17, 18]. Thorough Testing is conducted to verify proper functionality, data accuracy, and error handling. Finally, the Deployment phase involves deploying the web application to a hosting server or cloud platform, configuring necessary server settings, and ensuring accessibility for users.

In the Mobile Application Implementation process, the initial step involves Requirement Analysis, where specific requirements for the mobile application are identified, emphasizing user experience and mobile-specific features. This phase also defines how the mobile app will interact with the backend system and the Genetic Algorithm. Moving to UI Design, the focus is on creating an engaging user interface and experience. This includes designing mobile-friendly layouts, navigation structures, and interactive elements to enhance user interaction(refer to Figure 7).

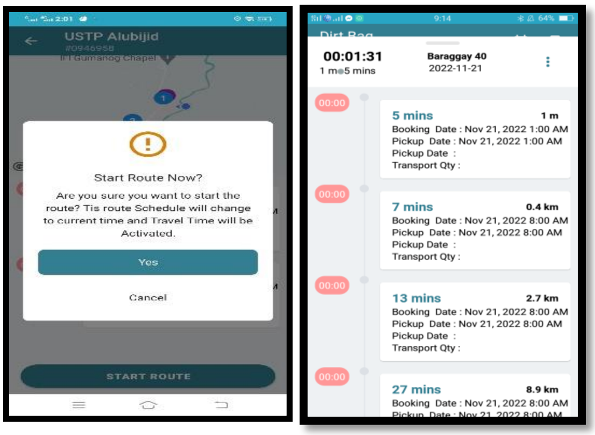

Figure 7 User Interface

Frontend Development follows, incorporating suitable frameworks or technologies, such as React Native for cross-platform development. Features are implemented to allow users to input pickup and drop-off details, view optimized routes, and receive real-time updates. Integration with the Backend is a critical step, requiring the mobile app to connect seamlessly with the backend system through defined APIs, ensuring efficient data communication. Geolocation Services are then implemented to track the current location of vehicles and dynamically update routes based on real-time conditions(refer to Figure 8).

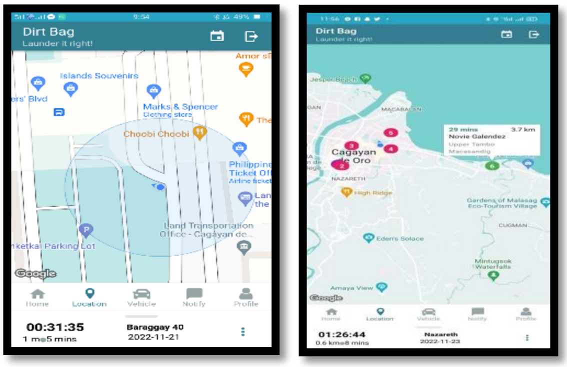

Figure 8 Vehicle location and route

5. RESULTS AND DISCUSSIONS

The final routes are produced and plotted (Figure 9).

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[[], [4, 3, 19, 5, 12, 2], [15, 1, 8, 16, 17, 20, 11],
[7, 10, 14, 6, 13, 18, 9]].
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The empty set [] represents the vehicle that will not be needed based on the solution.

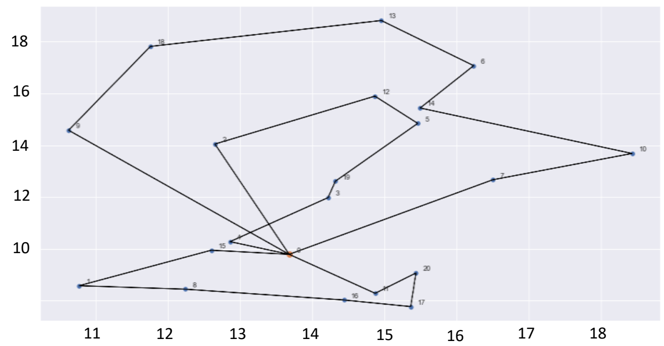

Figure 9: Plotted Routes produced by GA

Utilizing a Genetic Algorithm (GA), computations were performed for both the dynamic pickup route and the static drop-off route[15, 16]. Subsequently, the GA served as a pivotal route optimization module during the creation of the web and mobile applications for the pickup and drop-off delivery system. This integration was seamlessly incorporated into the Laundry System, as depicted in Figures 9, 10, and 11.

The process of route clustering involved a manual approach, where boundaries or clusters were delineated by clicking on points on the map, as illustrated in Figure 9.

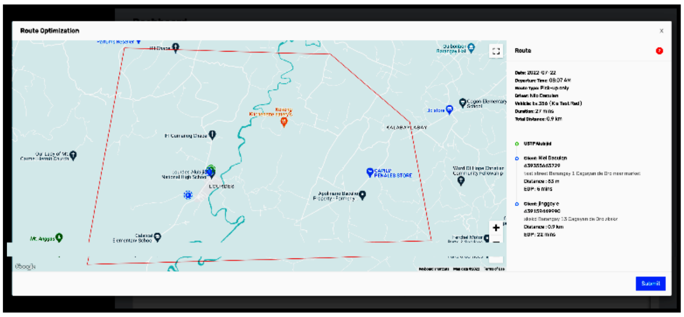

Figure 10: Route Clustering

Figure 11: Delete route note during enroute

While the vehicle is in transit, the dynamic route is activated, encompassing the actions of both removing and inserting nodes within the route. The removal typically occurs in response to client notifications of appointment cancellations or rescheduling of pickup appointments. Conversely, node additions take place when a new pickup request is identified within the Estimated Delivery Time (EDT) period, as illustrated in Figure 11.

Route plan is also reflected in the mobile application used by vehicle drivers as a guide route (Figure 12). The location of the driver can also be monitored in the web application of the admin.

6. CONCLUSION AND RECOMMENDATION

The implementation of a Genetic Algorithm (GA) to develop an optimized route plan for pickup and drop-off deliveries has

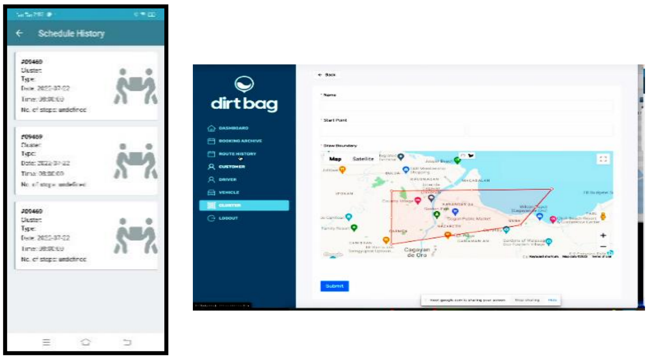

Figure 12: Driver's Mobile App Route Plan

proven to be a highly effective solution in minimizing travel costs while accommodating the growing clientele. Specifically, with an initial allocation of 4 vehicles for the route, the GA successfully optimized the plan to utilize only 3 vehicles, showcasing 75% of a significant potential impact on the company's operational costs. The introduction of a dynamic route plan was also successful, as evidenced by real-time updates on both the web and mobile platforms when adding or removing nodes (new pickup requests) during vehicle transit within the Estimated Delivery Time (EDT) period. Any new pickup requests beyond the EDT period are systematically queued for the next scheduled pickup. However, it is important to note that this study exclusively addresses route and vehicle capacity within time constraints. For a more comprehensive approach, we recommend further research incorporating artificial intelligence to handle factors such as traffic conditions, rerouting due to road maintenance, and other road-related situations that could potentially alter the route plan in real-time..

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