G-Tech : Jurnal Teknologi Terapan
Vol. 9, No. 1, 2025, p. 1-10
E-ISSN: 2623-064X | P-ISSN: 2580-8737

Web-Based Logistics Scheduling System Utilizing Cheapest Insertion Heuristic Algorithm

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Article Information

Article History

Received : October 8, 2024
Revised : November 11, 2024
Published: January 2, 2025

***Keywords*:**
Cheapest Insertion Heuristic,
Google Maps API,
Logistic scheduling system,
RAD methodology,
Route.

ABSTRACT

Efficiency in the logistics process is essential to maintain company credibility. Significant improvements in logistics efficiency can be achieved by integrating information systems. However, several companies have not implemented this system. These companies will face logistical challenges, especially in scheduling, which will cause delays in the delivery of goods. Against this challenge, this research aims to build a web-based information system to optimize logistics scheduling. This system aims to provide drivers with a compelling sequence of delivery points by applying the Cheapest Insertion Heuristic algorithm, which is integrated with the Google Maps API. This system will undergo a prototyping phase with a web-based approach using the Laravel framework, supported by PHP and MySQL for database management. This design will follow the Rapid Application Development method. User Acceptance Testing shows an average satisfaction score of 98%, which indicates that users feel significantly helped by the information system, especially in improving the company's delivery scheduling process.

INTRODUCTION

Effective logistics management is critical to a company's success. Logistics is essential because it ensures operational efficiency, reduces costs, and increases customer satisfaction through on-time delivery and goods in good condition (Burity, 2021). Good logistics provide a competitive advantage by offering faster and more effective services and supporting business adaptability and scalability (Noor, 2022). Additionally, good logistics management helps in risk management and is critical to supporting e-commerce growth and meeting customer expectations for fast delivery (Costa, 2020).

Information systems play an essential role in efficient scheduling. Information systems improve logistics and on-time delivery and improve operational effectiveness (Modgil & Sharma, 2017). Logistics scheduling can be inefficient and prone to human error without an information system (Wang, 2022), causing delays and increased operational costs. Efficient scheduling is a top priority because it can result in significant cost savings (Lee et al., 2023).

Manual scheduling has several negative impacts. The lack of transparency makes it difficult to track the delivery status in real-time (Sunny et al., 2020), while poor communication between teams and logistics partners can slow response to changes or issues (Kovács & Falagara Sigala, 2021). It also lacks flexibility in responding to sudden changes, resulting in suboptimal use of resources and inappropriate decision-making (Manzano & Soliven, 2021). As a result, a company may experience reduced efficiency, increased costs, and customer dissatisfaction, which harms its performance and competitiveness.

A previous study investigates the shortest route and distance for shipping goods using the Cheapest Insertion Heuristic (CIH) algorithm in the Traveling Salesman Problem. Compared to the route used by SiCepat Express Baleendah, the CIH algorithm produces a more efficient route, with 27.48% better efficiency. The Asymmetric TSP CIH application determines the shortest route and distance, resulting in a more efficient delivery process (Fargiana et al., 2022). PT Aksara Solopos, a daily newspaper publishing company, solves the Capacitated Vehicle Routing problem using the Cheapest Insertion Heuristic and sweep algorithms. The sweep algorithm includes customer grouping and route formation, while the CIH algorithm minimizes the insertion weight. This research uses historical data and geographic coordinates to determine the number of agents, a distance matrix, and a time window for newspaper delivery, ensuring delivery in less than 5 hours following the company's time window policy. (Nusantara et al., 2023). Modified CIH is a modified TSP algorithm to solve the general problem of arranging the order of places to be visited, especially for foreign tourists visiting the city of Medan. This method inserts the cheapest weights from two points until all locations are connected and remain stable even with significant inputs (Rachmawati & Wilyanto, 2020). Alternative metrics for algorithm evaluation include Efficiency (Fargiana et al., 2022), Average percentage increase (Renaud et al., 2000), total distances (Diana & Dessouky, 2004), Dependence of the error (Alatartsev et al., 2013), and total times (Kytöjoki et al., 2007).

Those previous researchers never applied CIH to the Logistics Scheduling System in the chemical industry. Therefore, this research fills the gap by applying CIH in this area. We also transition from manual to automated processes, enhancing operational efficiency and reducing the likelihood of human error. This automation will eliminate manual calculations, significantly improving efficiency, accuracy, and user experience. In addition, this paper proposes a web-based information system that automates the entire process. Integrating the Google Maps API, the system automatically calculates distances between delivery points and optimizes routes using the Cheapest Insertion Heuristic algorithm.

LITERATUR REVIEW

Cheapest Insertion Heuristic

Cheapest Insertion Heuristic is an algorithm recognized for effectively solving route optimization problems. This algorithm constructs routes with the shortest paths and minimal weights, sequentially adding them to the existing route. The algorithm achieves this by selecting the latest point and determining the minimum insertion cost by choosing an edge. Hence, the name Cheapest Insertion Heuristic. The algorithm follows a set of steps, including (Nusantara et al., 2023):

1. Initialization: The Algorithm begins with the starting point, which will be connected to the final point.
2. Subtour Creation: A subtour is formed between the initial and final points. A subtour represents a route that starts and ends at the same point, for example, (1,3) - (3,2) - (2,1), as illustrated in Figure 1.
3. Arc Replacement: One of the directional connections (arcs) between two points is replaced with a combination of two arcs: (i, j) with (i, k) and (k, j). The selection of 'k' is made from the points not yet included in the subtler and possesses the smallest additional distance. This distance is computed using the formula: $\boldsymbol{cik + ckj - cij}$ where $\boldsymbol{cik}$ is the distance from point 'i' to point 'k, $\boldsymbol{ckj}$ is the distance from point 'k' to point 'j,' and $\boldsymbol{cij}$ is the distance from point 'i' to point 'j.'
4. Iteration: Steps 3 are repeated until all points are incorporated into the subtour.

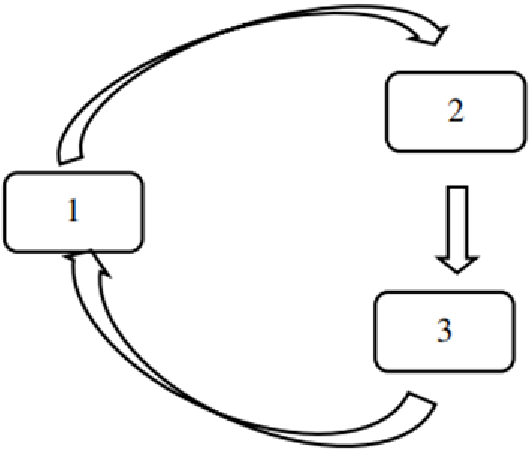

Figure 1 Subtour Model (Hignasari & Mahira, 2018)

Google Map API

Google Maps boasts a programming function, an Application Programming Interface (API), which is highly adaptable for integration into web applications or software currently in development (Solpieva, 2023). This integration is particularly valuable for applications requiring the seamless inclusion of map-related features. The capabilities offered by Google Maps API are instrumental for various purposes requiring map functionalities. To unlock these capabilities, developers must acquire a unique identification code, called an API key, directly from Google. This key acts as a secure and personalized gateway, ensuring developers can harness the full potential of Google Maps features within their applications. API keys add a layer of security and control, allowing developers to tailor the integration to their application requirements (Fargiana et al., 2022).

In the usage of Google Maps API in the research of information systems for the company, Google Maps API has many features that can be chosen. In this research, the features used for developing an information system for the company are: (1) Map Display functionality within the Google Maps API seamlessly integrates dynamic maps into web applications and software interfaces (Tadas & GA, 2024). (2) The geocoding feature within the Google Maps API allows the conversion of addresses into accurate geographic coordinates, precisely latitude and longitude (Serere et al., 2023). (3) Routes API functionality in the Google Maps API empowers developers to generate precise and optimized directions between specified locations (Solpieva, 2023). (4) Distance Matrix functionality within the Google Maps API empowers developers to compute travel distances and durations between multiple origin-destination pairs (Xie et al., 2024). (5) Static Maps functionality within the Google Maps API facilitates the creation of static map images that can be effortlessly integrated into applications without user interaction (Degbelo et al., 2020). (6) JavaScript API within the Google Maps API empowers developers to craft exceptionally interactive and dynamic maps using JavaScript (Chandra & Dwivedi, 2022).

METHODS

In this conducted research, the subject of study is PT. Karunia Primakimia Megah (KPM). The company operates within the chemical industry, selling various chemical products to other businesses. This company is engaged in B2B transactions for its business operations. This company has experienced a considerable volume of transactions. Records have been manually maintained throughout their product sales process, and the owner still engages in manual sales documentation. For the procurement of chemical products, the company currently places orders through the company's salespersons or directly with the company. The chemical inventory, stored within the company's warehouse at the same address as the company itself, consists of various chemical products. Upon a product's sale, it is packaged in barrels and delivered by drivers operating trucks, transporting the goods to the purchasing companies.

The RAD methodology's information system development process consists of four stages: Requirements Planning Stage, User Design Stage, Construction Stage, and Cutover (Enzelin et al., 2024), as shown in Figure 2. Requirements Planning Stage is carried out from October to November 2023. Interviews and observations are conducted to collect business processes and user needs. User Design Stage includes creating diagrams using tools such as Figma for system and database design using XAMPP and MySQL. The construction Stage comprises building a system with Laravel, the Cheapest Insertion Heuristic algorithm, and Google Maps API using PHP, HTML, and CSS in Visual Studio Code. The Cutover Stage includes Algorithm Evaluation and User Acceptance Testing by three system users to assess functionality and obtain feedback for system improvements. Evaluation of the algorithm performance is the efficiency of the distance with the algorithm compared with the distance without applying the algorithm. This evaluation is used in some previous research.

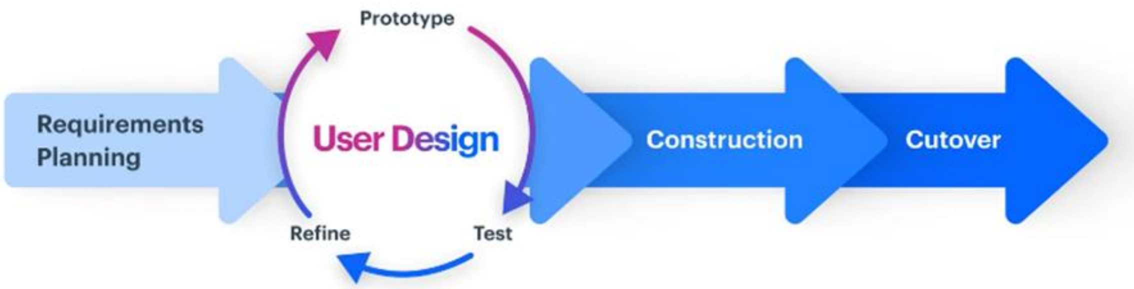

Figure 2 RAD Methodology (Johan et al., 2023)

RESULTS AND DISCUSSION

Requirement Planning and User Design

Some suggested functionality includes (a) implementation of an automated system to determine delivery routes and delivery sequences, (b) integration with Google Maps API to display distribution maps of delivery locations, and (c) inclusion of a delivery history viewing feature for easy access to previous delivery information. (d) user-friendly process for adding new delivery locations into the system, and (e) an easy-to-understand process for determining efficient delivery sequences using specific algorithms.

In the use case diagram in Figure 3, there are two main actors: admin and user. Admins have full access to all features in the information system, including driver data management and client location. However, users can only access other features. The use case comprises: (1) Managing Driver Data provides functions for managing data from drivers owned by the company. Admins can add, change, and delete driver data. (2) Displays Driver Data displays a list of drivers in the company. (3) Manage Client Location Point Data provides functions for managing data from client location points owned by the company. Admins can add, change, and delete client location point data. (4) Displays Client Location Point Data displays a list of client location points stored in the database. (5) Create a Sequence of Delivery Location Points: Create a sequence of delivery locations for which the driver will deliver. (6) Displays Estimated Travel Time displays estimated travel time estimates generated from the API and provides data about estimated travel time. (7) Create a Delivery Route Letter, a delivery route letter containing a sequence of delivery location points that can guide the driver in delivery. (8) Displays Delivery History displays deliveries made by the user. This feature shows the driver's name and the delivery order in list form.

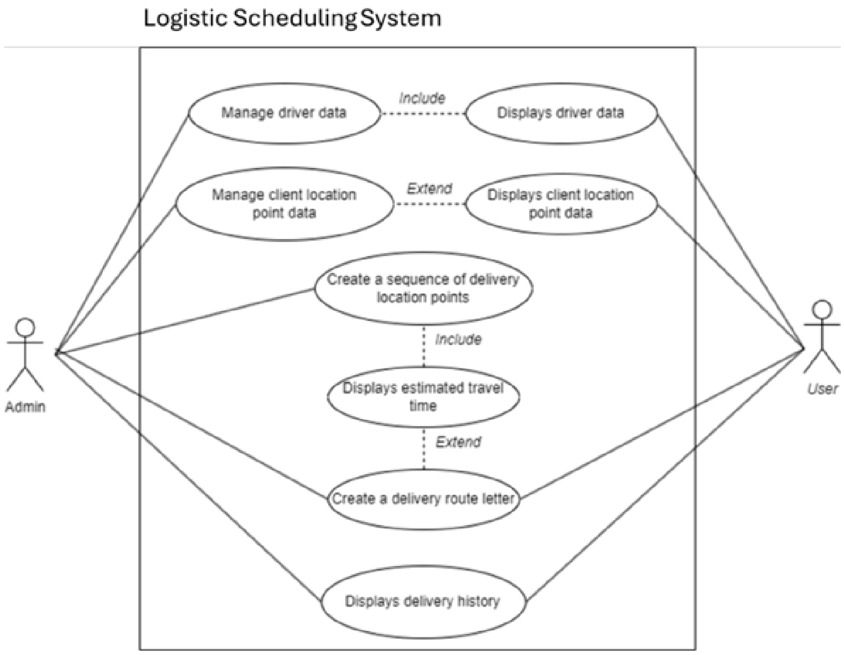

Figure 3. Use Case Diagram

Construction

In Figure 4, as an entry and display route for delivery, there is a dropdown menu displaying all registered locations and these points on the map. Once the area is selected, the user must select the driver for delivery from the dropdown menu. After this selection, the user can press the "Create Delivery" button to create a route and sequence, starting from the location point in the company. The user can also make a delivery route letter and save the delivery history.

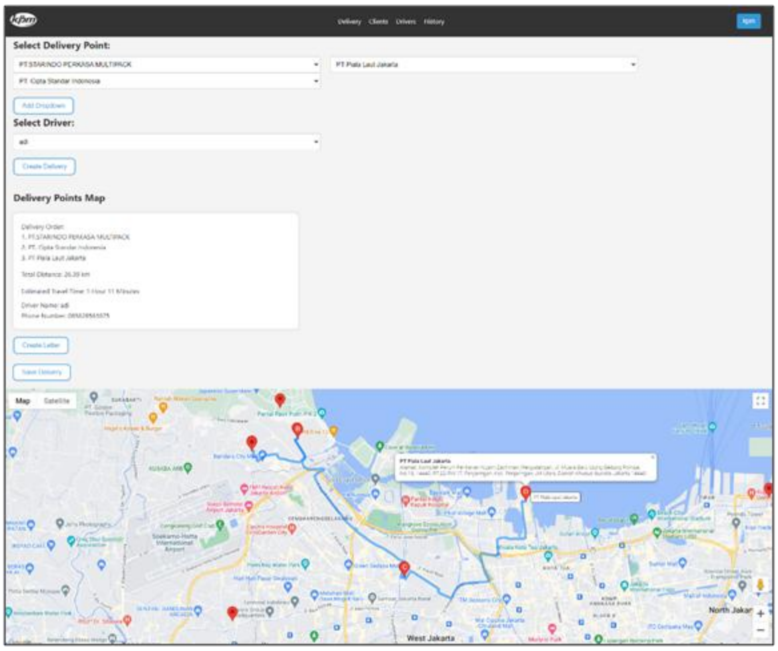

Figure 4. Feature of Create a Sequence of Delivery Location Points

Cut Over - Algorithm Evaluation

The test was conducted in three cases, delivering products from PT. KPM (labeled as A) to three different companies. In each case, the route without the algorithm is the usual route, while the route with the algorithm is obtained from the Website. Figures 5 to 7 show the Subtour Model for Cases 1, 2, and 3. The initial route without using the Algorithm is A-B-C-D. The algorithm can shorten the route, forming new routes for each case: A-B-D-C, A-D-B-C, and A-D-C-B.

Figure 5. Subtour Model for Case 1

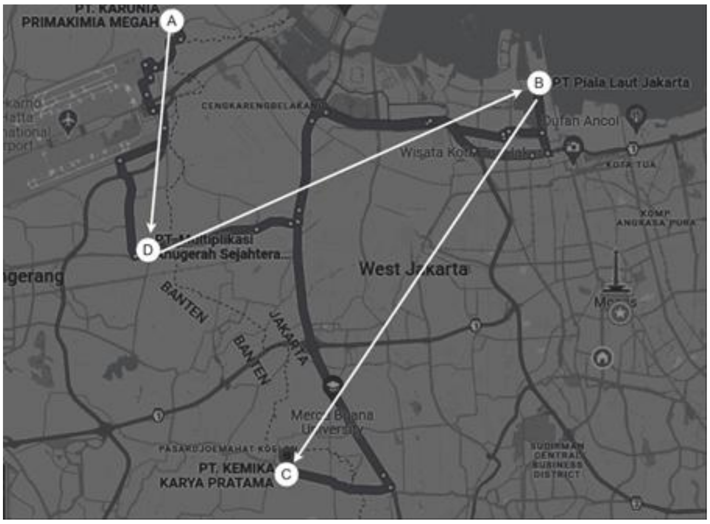

Figure 6. Subtour Model for Case 2

Figure 7. Subtour Model for Case

Table 1 shows the three cases comparing route results without the algorithm and with the algorithm. The algorithm helps the route delivery efficiency. For case 1, the route is scaled down from 33.3 km to 26.3 km or 21.02 efficiency. Case 2 reached 21.08% efficiency. The third case gains the most significant efficiency, with 29.5%. In previous research, the comparison between without the application reached 18.55 km and using the application reached 13.45 km, so the efficiency achieved was 27.48% (Fargiana et al., 2022). This research can be said to be successful because the best efficiency we obtained was 29.5%. This efficiency value has exceeded the efficiency of previous research.

Table 1. Route Comparison of With and Without Algorithm

Case	Location	Without Algorithm		With Algorithm		Efficiency
		Route	Distance	Route	Distance	
Case 1	PT. KPM (A) PT. SPM (B) PT. PLJ (C) PT. CSI (D)	A-B-C-D	33.3 km	A-B-D-C	26.3 km	21.02%
Case 2	PT. KPM (A) PT. PLJ (B) PT. KKP (C) PT. MAS (D)	A-B-C-D	66.4 km	A-D-B-C	52.4 km	21.08%
Case 3	PT. KPM (A) PT. PMD (B) PT. TMP (C) PT. MAS (D)	A-B-C-D	113.1 km	A-D-C-B	79.7 km	29.50%

Cut Over - User Acceptance Test

Testing will be conducted by three users using Black Box Testing with UAT on the Website. UAT consists of five criteria, from Strongly Agree (SA) weight 5 to Disagree (SD) weight 1 Strongly. The result of the UAT is shown in Table 2. The average percentage of results for all questions shows an overall score of 98%. This result expresses satisfaction and felt helped by the designed information system, which proved helpful for the company's delivery scheduling process.

Table 2. UAT Result

No	Questions	Score					Total	Average	Percentage
		SA*5	A*4	N*3	D*2	SD*1			
1	Does the login process run smoothly?	3					15	5	100%
2	Does the list of drivers displayed on the system provide appropriate information?	3					15	5	100%
3	Does the client list displayed on the system provide appropriate information?	2	1				14	4.6	92%
4	Does adding, deleting, and changing driver data run smoothly, and are they easy to use?	3					15	5	100%
5	Does adding, deleting, and changing client data run smoothly?	2	1				14	4.6	92%
6	Does creating delivery routes run smoothly and be easy to use?	3					15	5	100%

7	Is the information about the order of delivery location the following requirements?	3					15	5	100%
8	Does the information about delivery routes produced by the system match your needs?	3					15	5	100%
9	Is the information about total travel time produced by the system following requirements?	3					15	5	100%
10	Does the system output as a delivery route letter meet your needs?	3					15	5	100%
11	Is the information displayed on the delivery route letter appropriate to your needs?	3					15	5	100%
12	Is the information displayed on the history page appropriate to your needs?	2	1				14	4.6	92%

CONCLUSION

The research findings underscore significant benefits both in practical and academic realms. From a practical perspective, successfully implementing the Cheapest Insertion Heuristic algorithm within the web-based logistics scheduling system offers tangible efficiency improvements, exemplified by a notable 23.87% enhancement in route optimization. It directly translates into streamlined logistics processes for the company, allowing for more precise delivery scheduling and resource utilization. Moreover, the system's ability to integrate seamlessly with Google Maps API enhances its practical utility, providing accurate location data and route visualization for improved decision-making. Thus, the research outcomes bear immediate practical implications by offering a robust solution to the company's logistical challenges, ultimately fostering operational efficiency and cost-effectiveness.

From an academic standpoint, the research contributes invaluable insights into applying algorithmic techniques within real-world logistics management scenarios. By leveraging the Cheapest Insertion Heuristic algorithm and conducting thorough Black Box Testing, the study validates the efficacy of algorithmic solutions and sheds light on their practical implementation and performance evaluation methodologies. Furthermore, using Google Maps API as a foundational component underscores the relevance of contemporary technology integration in addressing complex logistical demands. Such findings enrich the academic discourse surrounding logistics optimization, offering a nuanced understanding of algorithmic approaches and their impact on operational efficiency. As a result, this research serves as a springboard for future investigations, guiding scholars and practitioners alike in pursuing enhanced delivery systems and logistical strategies through the synergistic application of technology and algorithmic methodologies.

ACKNOWLEDGEMENTS

We want to acknowledge and thank Universitas Multimedia Nusantara for their generous funding, which has greatly facilitated the progress and success of our research project.

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