OPT-TMS: a transport management system based on unsupervised clustering algorithms

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ABSTRACT

Transportation management within modern logistics has become increasingly complex, particularly with the expansion of industrial zones outside urban centers. This paper introduces OPT-TMS, a cutting-edge transportation management system (TMS) designed to optimize employee transportation using advanced machine learning techniques, specifically unsupervised learning and clustering algorithms. OPT-TMS integrates a comprehensive dataset that includes employee locations, entry times, bus capacities, and other critical parameters to enhance resource utilization, reduce costs, and improve overall efficiency. The proposed system follows a systematic workflow encompassing data collection, preparation, and adaptive clustering using the K-means algorithm with constraints. The innovative approach leverages real-time data integration through the open route services (ORS) API to optimize bus routes and collection points. Extensive validation, involving both data verification and physical testing, confirms the system's accuracy and effectiveness across multiple Moroccan cities, including Casablanca, Kenitra, and Marrakech. The development of OPT-TMS into a user-friendly web application further demonstrates its practical utility, offering decision-makers a dynamic tool for real-time adjustments and efficient transportation management. This paper concludes that OPT-TMS represents a significant advancement in transportation logistics, enhancing both employee satisfaction and operational efficiency through data-driven optimization.

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1. INTRODUCTION

Personnel transport is a crucial component of modern logistics, especially as industrial zones increasingly extend beyond city limits. Efficient management of personnel transport is essential not only for operational efficiency but also for ensuring employee satisfaction and productivity [1], [2]. As companies expand their operations, the challenge of optimizing transport systems becomes more complex. This involves addressing various factors such as determining the optimal routing for buses, calculating the appropriate number of buses required, maximizing bus capacity, and scheduling transportation to ensure timely and comfortable arrival for workers [3]-[6]. Despite its importance, the field of personnel transport has seen limited innovation, with many systems relying on outdated methods for tracking and managing employee movements. These traditional systems often struggle with optimization issues, leading to inefficiencies and higher operational costs [7]-[9].

Traditional personnel transport systems typically involve rudimentary applications where employees manually input their locations and work schedules. Transport administrators then use this information to allocate buses, a process that often results in suboptimal scheduling and inefficient use of resources [10]-[12]. Some systems have incorporated global positioning system (GPS) sensors for route optimization and monitoring [13], yet many still depend on outdated technology and manual interventions. For instance, Gao and Liu [14] developed a vehicle trajectory tracking system utilizing mobile data to monitor speed, position, and turning behaviors. This system provides real-time insights but requires significant manual oversight. Similarly, Bolla and Davoli [15] created a traffic simulation model using mobile phone data, Fontaine and Smith [16] developed a test bench with a traffic simulation model, and Bucher *et al.* [17] presented a method for creating vehicle trajectory profiles from mobile phone position data. While these advancements represent progress, they often come with high installation and maintenance costs and still require considerable human management.

The emergence of the internet of things (IoT) and advancements in electronics offer promising avenues for enhancing personnel transport systems. Intelligent transport management systems (TMS) leveraging these technologies can provide real-time tracking, automated decision-making, and improved efficiency. Smart cities like New York and Dubai have begun integrating such systems, utilizing a network of sensors and real-time data processing to optimize urban mobility and operational efficiency [18]-[23]. These systems represent a significant leap forward but are still confined to a limited number of smart cities. The majority of urban and industrial areas lack such comprehensive infrastructure, highlighting a critical gap in current transport management practices.

In light of these challenges, this paper proposes a novel approach to personnel transport optimization through the application of machine learning techniques, specifically unsupervised learning and clustering algorithms. Unlike traditional methods, the proposed system aims to leverage advanced data analysis to enhance decision-making processes, reduce operational costs, and improve overall efficiency. By integrating these machine learning techniques, the system offers a scalable solution adaptable to various technological contexts, addressing the limitations of existing systems and providing a path toward more efficient and intelligent transport management. This research contributes to the field by presenting a new paradigm for personnel transport management that aligns with contemporary technological advancements and addresses the shortcomings of traditional systems. The paper details the development and application of this approach, highlighting its potential to transform personnel transport practices in both existing and emerging industrial settings.

2. METHOD

2.1. Proposed approach

The proposed approach introduces OPT-TMS, an innovative transportation management system (TMS) designed to transform personnel transport operations through advanced optimization and machine learning techniques. OPT-TMS aims to improve operational efficiency, resource utilization, and cost-effectiveness in managing employee transportation by leveraging sophisticated algorithms and real-time data analysis. OPT-TMS operates through a systematic workflow, as illustrated in Figure 1, which includes several key phases:

Step 1: data collection

In the initial phase, OPT-TMS gathers essential data required for optimizing transportation logistics. This data includes:

- Employee coordinates: precise geographic coordinates (latitude and longitude) of each employee's location.
- Time of work entry (TW): the scheduled time at which employees are expected to start work.
- Maximum time for bus turn (MTT): the maximum allowable time for buses to complete their routes and turn around.
- Maximum walking distance (MWD): the furthest distance employees are expected to walk from their pickup or drop-off points.
- Bus capacity (BC): the maximum number of employees that each bus can accommodate.
- Number of buses (NB): the total number of buses available for transportation.

This data forms the foundation for subsequent analysis, ensuring that all critical parameters are considered in the optimization process.

Step 2: data preparation and adaptation

After data collection, the data undergoes meticulous preparation to ensure its quality and relevance:

- Handling missing values: missing or incomplete data entries are addressed through removal or imputation techniques, depending on the extent and nature of the missing data.

- Data consistency: the coordinate system and units used across the dataset are standardized to ensure consistency. This step involves verifying and correcting any discrepancies to maintain accurate data throughout the process.
- Data integration: combining data from various sources (e.g., employee locations, schedules) into a unified format that facilitates further analysis.
- Proper data preparation is crucial for the integrity of the optimization results and the overall effectiveness of the system.

Step 3: group construction using K-means with constraints

The core functionality of OPT-TMS involves clustering employees into optimal groups using the K-means algorithm [24], enhanced with parameter optimization:

- Initial parameter setup: the number of clusters (Nb_clusters) is initially estimated based on the ratio of the employee list size to bus capacity (size (list (X, Y)) / BC). This estimation provides a starting point for clustering.
- K-means clustering: the K-means algorithm partitions the employee data into clusters based on distance. It assigns each employee to the nearest cluster centroid and iterates to update the centroids based on the mean position of the assigned employees. The process continues until the algorithm converges or reaches the maximum number of iterations.
- Constraint checking: post-clustering, the system evaluates whether the clusters meet predefined constraints, including MTT and MWD. If the constraints are not satisfied, the algorithm adjusts the number of clusters (Nb_clusters) and repeats the clustering process.
- Adaptive optimization: the algorithm dynamically adjusts the number of clusters and re-evaluates the constraints to ensure optimal grouping. This iterative approach balances minimizing the number of clusters with meeting all constraints, thus improving the system's efficiency.

Finally, OPT-TMS offers a scalable and adaptive solution that evolves with the changing needs of transportation management, ultimately achieving greater efficiency and cost savings. Through these detailed steps, OPT-TMS provides a comprehensive solution for optimizing personnel transport, leveraging data-driven insights and advanced algorithms to enhance overall operational performance.

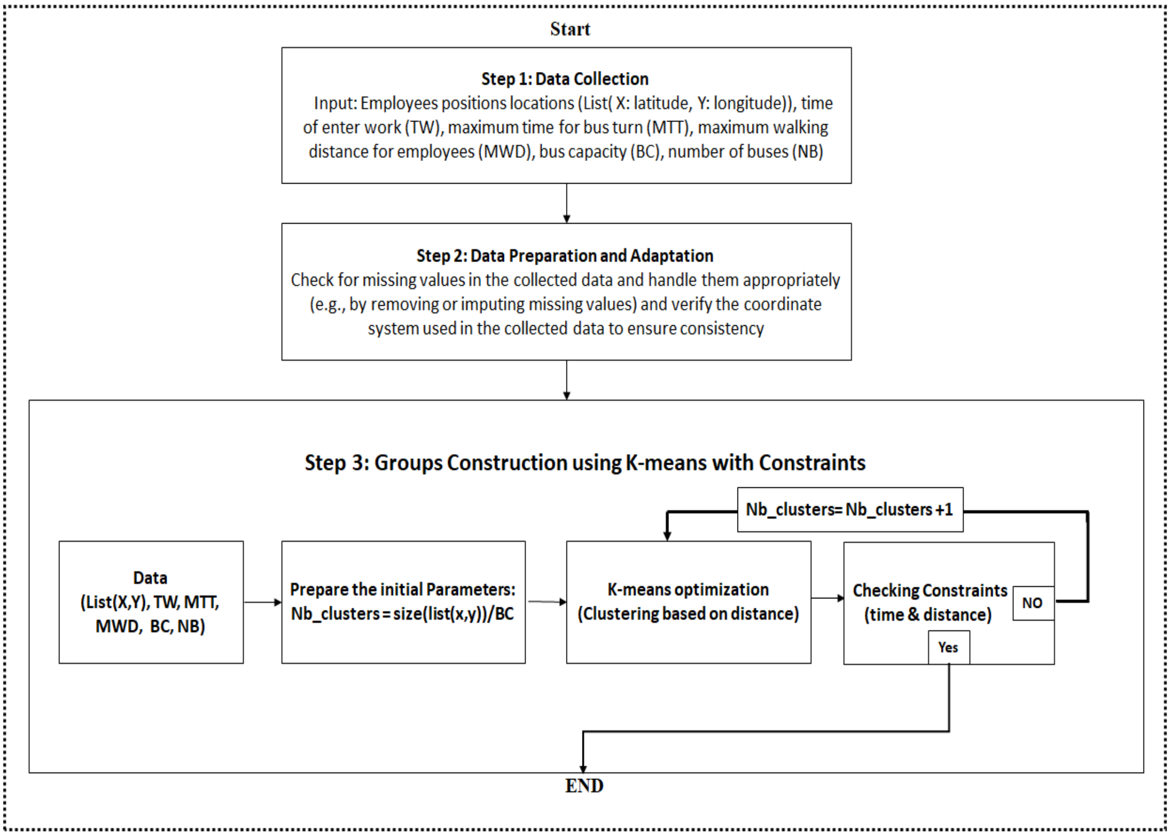

Figure 1. Workflow of the proposed approach

2.2. Data collection

To develop and validate the OPT-TMS, we collected a comprehensive dataset from an anonymous logistics and transportation management company based in Casablanca, Morocco. This dataset is crucial for constructing and evaluating the system's optimization capabilities. The collected data includes:

- Employee locations: latitude and longitude coordinates representing the locations of numerous employees in Casablanca. This spatial data is essential for understanding the distribution of employees across the city and forms the basis for clustering and route optimization.
- TW: the scheduled time at which each employee is expected to begin their workday. This temporal information is vital for planning transportation schedules and ensuring that buses arrive on time.
- MTT: the maximum allowable time for buses to complete their routes and turn around for the next trip. This constraint helps in planning efficient bus routes and managing turnaround times.
- MWD: the maximum distance employees are expected to walk from their pickup or drop-off points. This data is used to ensure that walking distances are minimized, improving employee convenience.
- BC: the maximum number of employees that each bus can accommodate. This information is crucial for determining how many buses are needed and for effective grouping of employees.
- NB: the total number of buses available for transportation. This data helps in planning the distribution of employees across available buses and optimizing bus routes.

Figure 2 provides a map view showcasing the spatial distribution of employee coordinates across Casablanca. This visual representation allows for a clear understanding of the employee locations and is instrumental in identifying clusters and optimizing bus routes. By analyzing this spatial data, OPT-TMS can:

- Identify clusters: determine areas with high concentrations of employees to streamline bus routes and improve collection efficiency.
- Optimize routes: use the spatial distribution data to plan optimal bus routes that minimize travel distances and time, while considering the maximum walking distance for employees.
- Visualize constraints: understand the geographical constraints and the spatial relationships between employee locations, which are crucial for effective transportation management.

In addition to spatial data, the collected information on bus capacity and number of buses enables OPT-TMS to optimize transportation logistics further:

- Route optimization: determine the most efficient routes for each bus, considering factors like distance traveled and bus turnaround times. This ensures that buses are utilized effectively, reducing operational costs.
- Resource allocation: optimize the allocation of buses based on the number of employees and their locations, ensuring that each bus is used to its full capacity while adhering to constraints like MWD and MTT.
- Efficiency maximization: enhance overall transportation efficiency by minimizing walking distances for employees and optimizing bus schedules to meet work entry times.

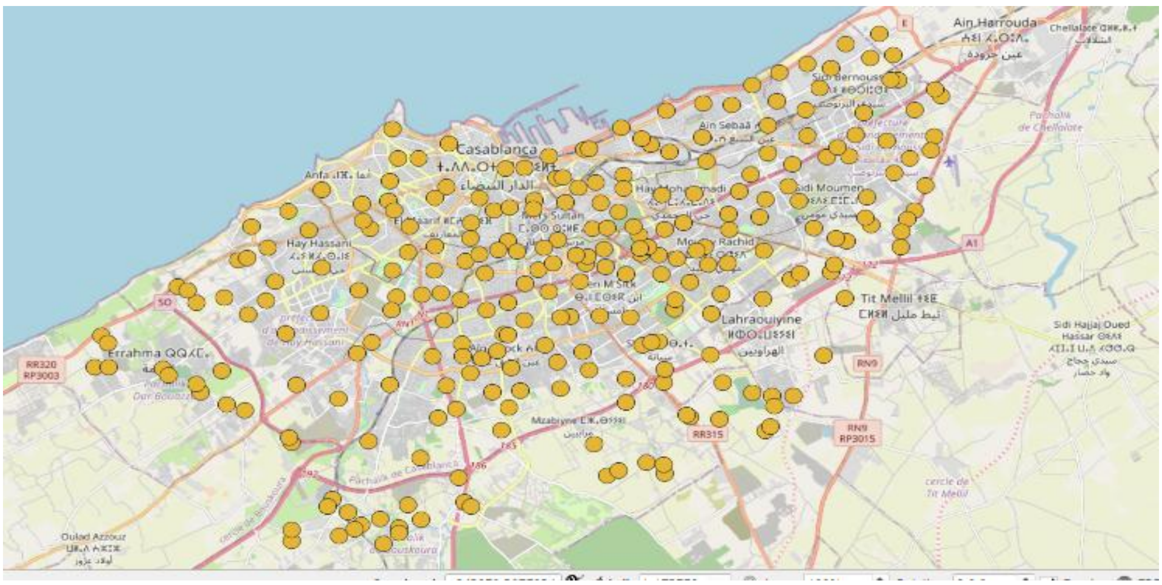

Figure 2. Employee locations

The integration of this comprehensive dataset allows OPT-TMS to apply advanced optimization techniques, such as the K-means algorithm, to group employees effectively and plan transportation logistics. The system's ability to analyze and adapt to real-world data ensures that the proposed solutions are practical and applicable to dynamic transportation scenarios as shown in Figure 3.

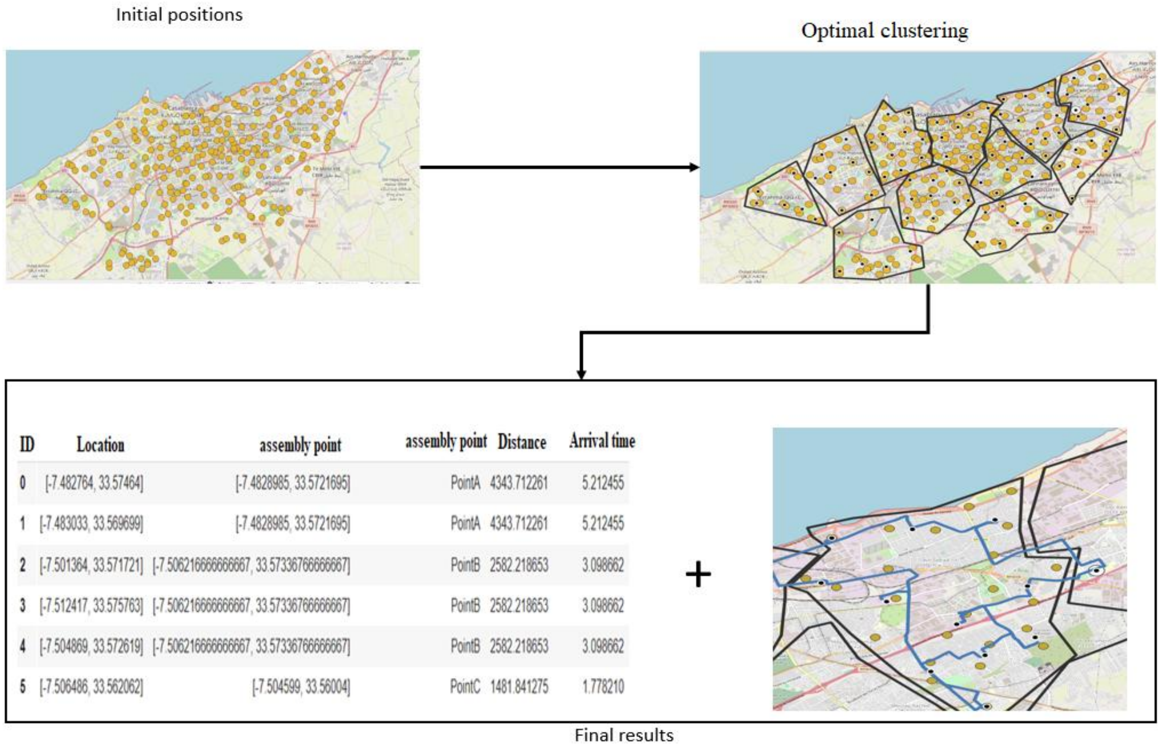

Figure 3. Input and output of our system

2.3. OPT-TMS development

The OPT-TMS is designed to optimize the clustering of employees based on proximity while addressing key constraints commonly faced in personnel management, such as collection time. Given the critical importance of punctuality to employee satisfaction, minimizing delays in the collection process is a primary goal of the system. By focusing on clustering employees based on their spatial distribution, OPT-TMS ensures that buses cover smaller areas, which facilitates quicker and more efficient employee collection.

The development of OPT-TMS involves several key steps. Initially, employees are clustered using the K-means algorithm, which groups individuals based on their proximity to each other. This approach reduces the area that buses need to cover, allowing for faster collection times. To further refine the clustering process, the system identifies optimal collection points, or centroids, that are strategically positioned to minimize walking distances for employees. This optimization is particularly critical as it ensures that buses are directed to the most effective collection points, reducing the time employees spend walking to these points.

Integral to the OPT-TMS is its integration with satellite information through the open route services (ORS) API. This integration provides real-time route optimization, allowing the system to deliver the most efficient itineraries to bus drivers. The ORS API helps determine the best routes to each collection point, taking into account current traffic conditions and other variables. By incorporating this real-time data, OPT-TMS ensures that buses follow optimized paths, reducing both travel time and distance. The system also uses information from the ORS API to communicate precise collection times to employees. This feature allows employees to be at their designated collection points at the right time, further enhancing efficiency and satisfaction.

To tailor the K-means algorithm to the specific needs of our system, we have customized it by experimenting with various parameter values. We focus on determining both the minimum and maximum number of clusters, considering the number of available buses as a limiting factor. The capacity of each cluster, which corresponds to bus capacity, is also taken into account. This customized approach ensures that the K-means algorithm can accurately predict clusters that adhere to our constraints, optimizing bus routes and improving overall transportation management. Overall, the OPT-TMS development process combines advanced clustering techniques with real-time route optimization to create a highly efficient and responsive TMS. This approach not only enhances operational efficiency but also significantly improves employee satisfaction by minimizing wait times and optimizing the transportation experience.

Technically, the developed K-means clustering algorithm as shown in Algorithm 1 aims to group data points representing the locations of employees into clusters, considering a specified number of clusters and a maximum size constraint. The algorithm begins by initializing the clusters. It then iteratively assigns data points to the nearest cluster centroid while respecting the size constraint, repeating this process for the desired number of clusters. Next, it assigns cluster indices to each data point. The algorithm determines the most common cluster assignment among the data points and assigns any unassigned data points to this most common cluster. Finally, it outputs the cluster assignments, indicating which cluster each person belongs to.

Algorithm 1. K-means constrained clustering

```
Input:
  - Data points : X = {(x_1, y_1), (x_2, y_2),...,(x_n, y_n)}
  - Max number of clusters
- Maximum size of each cluster
utput:
- Cluster assignments: C = {c_1, c_2, ..., c_n}
Step 1: Initialization
  Set clusters = [ ]
Step 2: Cluster Assignment
 Repeat Nbr_bus times:
   Set current_cluster = [ ].
   For each data point (x_i, y_i) in X:
      Assign (x_i, y_i) to the cluster with the nearest centroid that satisfies the
    constraint of not exceeding size_max.
   Append current_cluster to clusters.
Step 3: Cluster Index Assignment
 For each data point (x_i, y_i) in X:
    Assign the cluster index to each data point.
Step 4: Determine the Most Common Cluster Assignment
 Count the occurrences of each cluster index in C.
 Find the cluster index j with the highest count.
    Let most_common = j.
 Create a list unassigned = [ ].
 For each data point (x_i, y_i) in X without an assigned
 cluster index:
   Assign most_common to c_i.
   Add (x_i, y_i) to unassigned.
Step 5: Assign Unassigned Data Points
```

3. RESULTS AND VALIDATION

The OPT-TMS is an advanced system that leverages cutting-edge artificial intelligence techniques, particularly unsupervised learning, to optimize transportation management. The project began with an extensive data collection process focusing on employee locations within Casablanca. This comprehensive dataset included precise latitude and longitude coordinates of employees, time of work entry, bus capacity, and other critical parameters.

To ensure the accuracy and reliability of the dataset, a rigorous validation process was employed. This validation was conducted by a team of logistics experts familiar with Casablanca's unique landscape, ensuring that the dataset was meticulously reviewed. Google Maps was also used as a supplementary tool for data verification, enhancing the reliability of our dataset. This dual-validation approach ensured that the foundation of the OPT-TMS was both accurate and robust. Following the successful validation of data from Casablanca, the system was expanded to include data from other Moroccan cities such as Kenitra and Marrakech. The verification process was repeated for these extended datasets, maintaining consistency and accuracy across different locales. The data from these cities was integrated into the OPT-TMS, enabling the system to operate effectively across a broader geographic area.

The deployment of OPT-TMS on this extended dataset yielded two significant outputs: the formation of employee groups and corresponding maps for each group. To validate these outputs, a physical validation process was conducted, which involved traversing the proposed routes in a vehicle to check the temporal precision of each turn and the accuracy of assembly points. The results from this validation closely aligned with the system's predictions, with only minor discrepancies of one or two minutes observed.

Such minimal deviations are considered exceptional within the realm of TMS and are well within acceptable limits. The successful validation of OPT-TMS in Casablanca, Kenitra, and Marrakech underscores its robustness and adaptability. This success has attracted significant interest from various enterprises in Morocco, highlighting the system's potential as an intelligent solution for employee transportation management. In summary, the extensive validation efforts, which included both data verification and physical validation, affirm the reliability and accuracy of the OPT-TMS outputs. The system's successful application across multiple Moroccan cities establishes it as a viable and effective solution in the field of intelligent transportation management.

3.1. OPT-TMS web app

To enhance the accessibility and usability of OPT-TMS, we have developed a user-friendly web application as shown in Figure 4. The application was created using FLASK, a Python web framework, to build an interactive interface [25]. To facilitate seamless communication between the backend processes and the user interface, Django was integrated. This combination ensures efficient interaction between the system's core functionalities and the graphical interface.

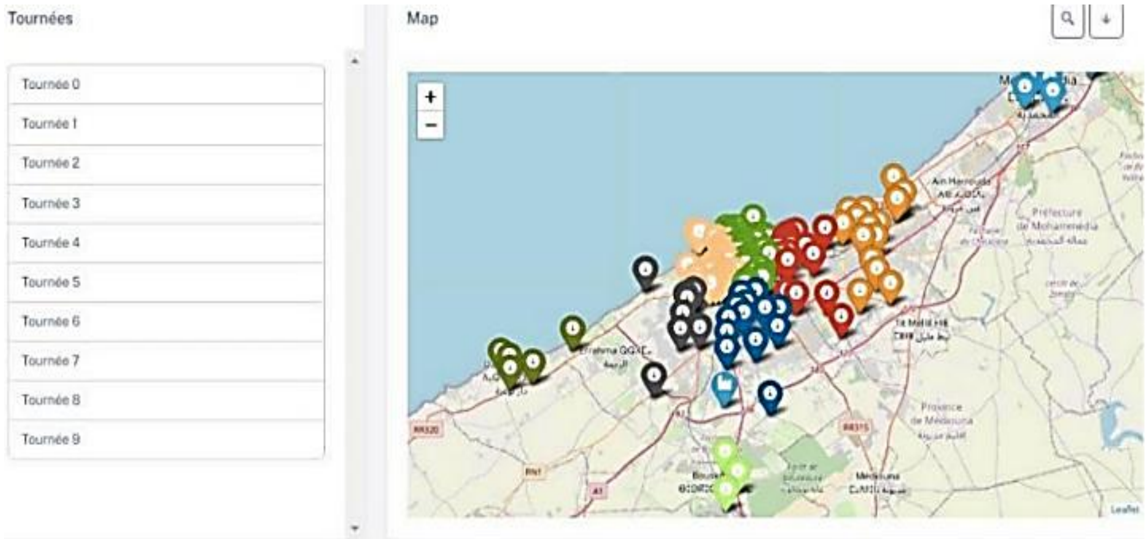

Figure 4. OPT-TMS web application

The web app hosts a dedicated folder for the database, which stores results, maps, and other relevant information. The system prompts users to upload a CSV file containing employee locations, IDs, and addresses. This data is used to extract coordinates (latitude and longitude) for processing. The system also requires inputs such as the coordinates of the factory (the bus departure point), bus capacity, maximum turn time, and the maximum walking distance from home to the assembly point. Users can choose from three execution modes: "rapid time," which prioritizes minimizing travel time; "minimum distance," which focuses on minimizing the distance traveled; and a hybrid option that balances both time and distance as shown in Figure 5.

Based on these inputs, the system initiates the optimization process, generating multiple groups that adhere to the specified constraints. The results are displayed as clickable buttons, allowing users to view detailed maps showing bus routes and assembly points. Additionally, an Excel file is generated, providing comprehensive information about each group, including assembly point times and bus IDs as shown in Figure 6. This file serves as a communication tool for informing employees about their assigned group, bus ID, and collection time.

The OPT-TMS web app addresses several logistical challenges by optimizing bus schedules, routes, and minimizing employee wait times. Figure 7 illustrates an example of the trajectory provided by the system. The application's adaptability is a key feature, allowing it to be launched and updated in real-time to accommodate changes in employee availability, working hours, and other variables. This dynamic capability empowers decision-makers to generate new results and adjust logistics efficiently, making OPT-TMS a versatile tool for advanced transportation management.

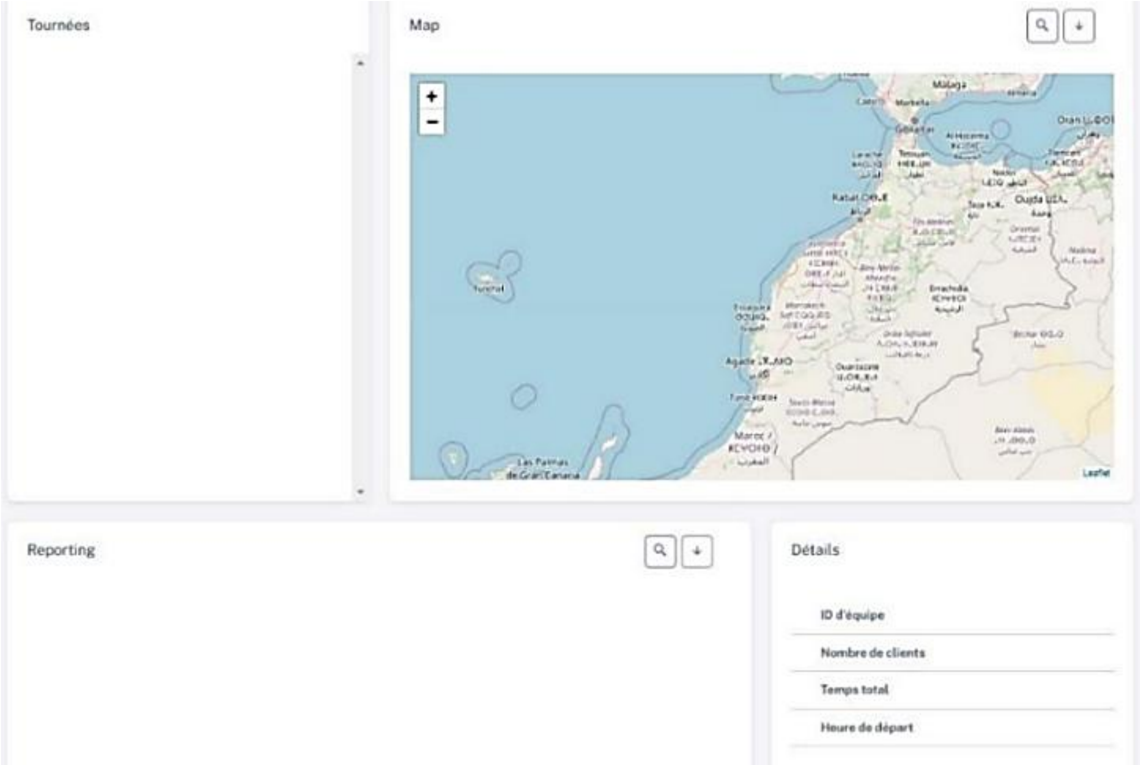

Figure 5. OPT-TMS inputs

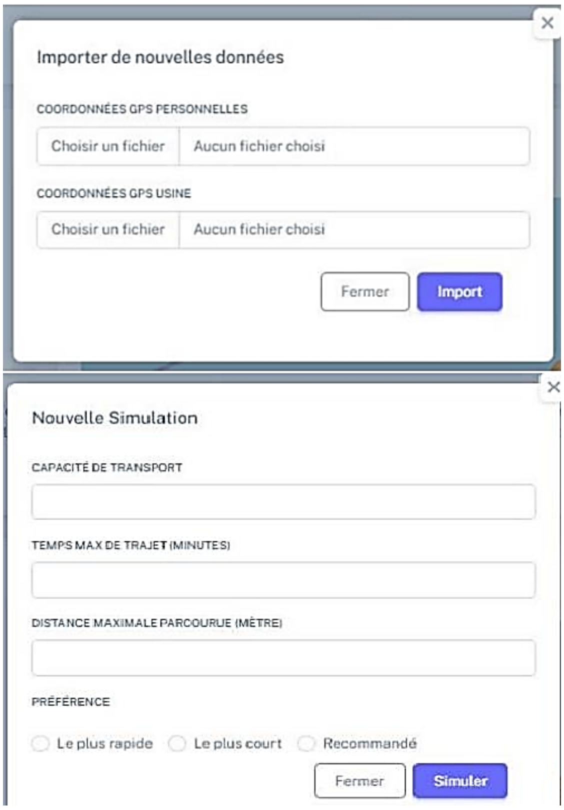

Figure 6. Employee groups results

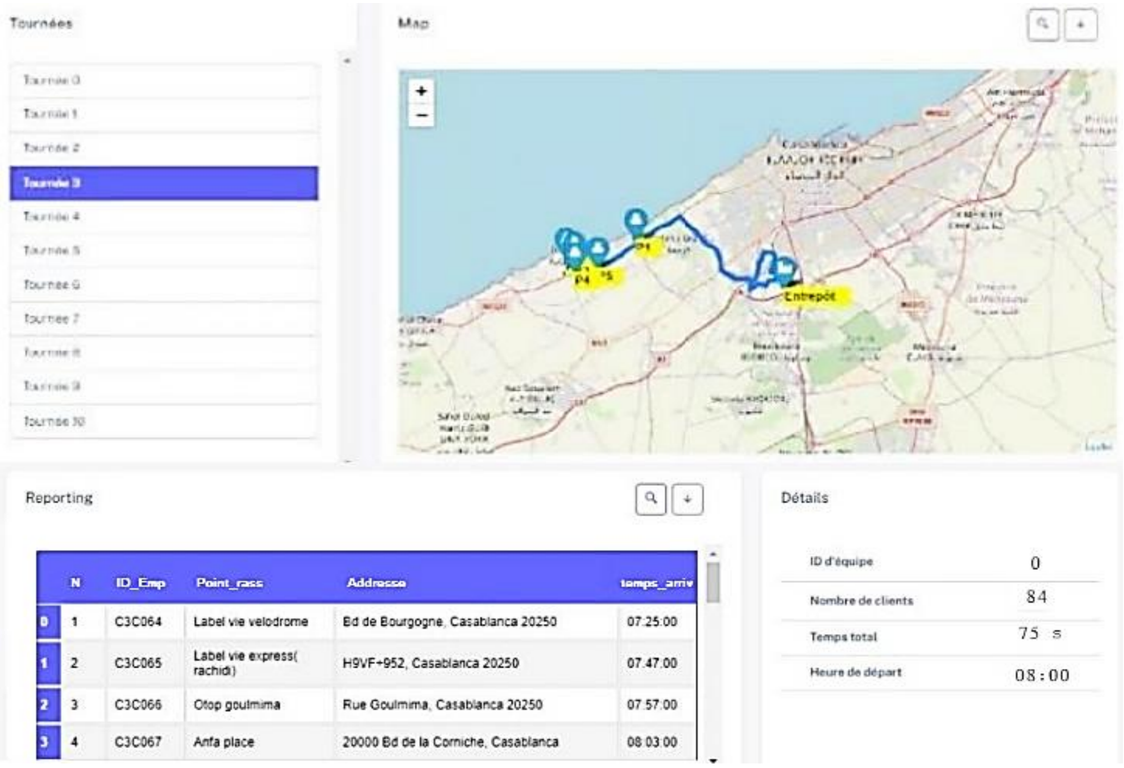

Figure 7. Example of a trajectory

4. CONCLUSION

OPT-TMS represents a significant advancement in transportation management, offering a new perspective on optimizing decision-making processes with unprecedented efficiency. This innovative system is built on a comprehensive dataset that includes essential details such as employee timings, distances, and geographic locations. By integrating unsupervised machine learning techniques with this data, OPT-TMS effectively creates optimal employee clusters and refines bus routes, leading to substantial improvements in transportation logistics. The strength of OPT-TMS lies in its ability to leverage data-driven insights to produce precise outputs, including exact pickup times and designated assembly points for employees. This level of detail ensures that transportation is not only punctual but also highly organized, providing each employee with a specific spot on the bus. The system exemplifies how technology and intelligence can work in tandem to address the complexities of transportation management, offering a powerful tool for decision-makers to navigate and optimize logistics. The flexibility of OPT-TMS allows for real-time adjustments, enabling the generation of updated groups and maps in response to changing employee schedules and operational needs. This adaptability ensures that transportation solutions remain relevant and effective, empowering decision-makers to address emerging challenges promptly. By optimizing transportation logistics, OPT-TMS enhances overall efficiency and boosts employee satisfaction.

Furthermore, the system’s integration with the transportation workforce is crucial. By facilitating efficient collection of employees and reducing the need for manual intervention, OPT-TMS not only improves resource allocation but also elevates the experience for both employees and decision-makers. The alignment of system predictions with real-world execution is reinforced by sharing output maps with bus conductors, ensuring seamless operation and enhancing the overall logistics experience. In summary, OPT-TMS sets a new benchmark for intelligent TMS. Its innovative use of data and advanced methodologies translates into actionable insights, enabling precise navigation of transportation logistics. This approach significantly enhances both operational efficiency and employee satisfaction, marking a significant advancement in the field of transportation management.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Soufiane Reguemali	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
Abdellatif Moussaid	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Abdelmajid Elaoudi	✓	✓	✓	✓						✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, M.A., upon reasonable request.

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