Optimizing Human Traffic Flow in Istanbul's Public Transportation System

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***Abstract*—To enhance the efficiency of human traffic flow within Istanbul's public transportation network, this project focuses on implementing strategic solutions to address issues such as overcrowding, lengthy waiting periods, and inefficient boarding procedures during peak hours. The initiative involves deploying advanced crowd management techniques, optimizing bus and metro schedules based on demand patterns, and upgrading station infrastructure to accommodate larger volumes of commuters. By comprehensively addressing these challenges, the project aims to streamline the travel experience, reduce congestion, and enhance the overall effectiveness of Istanbul's public transport system.**

I. INTRODUCTION

The aim of this project is optimizing human traffic flow in response to the pressing challenges faced by Istanbul's public transportation system, characterized by congestion, inefficiencies during peak travel hours, and environmental concerns. In addition to developing solutions to improve operational efficiency, the project also determines the optimal travel hours to minimize crowding on the "RAYLI" and "OTOYOL" environments by utilizing optimization techniques like Simulated Anealing, Particle Swarm Optimization, and Genetic algorithms. The project aims to improve the commuter experience by concentrating on important issues such as congestion, long wait times, and boarding processes. In addition to enhancing travel convenience, this project enhances Istanbul's livability.

II. PROBLEM DEFINITION

Istanbul, a city with a population of more than fifteen million, has severe problems with its public transit system, mostly because of increasing levels of human traffic congestion. The RAYLI and OTOYOL sectors of the network observe the worst congestion during peak hours, which results in long wait times, crowded transit vehicles, and general inefficiency in passenger service. Millions of people's everyday travels are made more difficult by these challenges, which also worsen environmental issues by increasing emissions and have an effect on public health by encouraging the spread of infectious illnesses. The physical structure of the city is also stressed by the present inefficiencies, which further lower the standard of living for residents. This report addresses these crucial issues by putting forth optimal ideas aimed to enhance traffic flow and the efficiency and long-term sustainability of Istanbul's public transportation system.

III. DATA

This section will address the procedures for collecting, arranging, and presenting the data that will be used for algorithms.

We utilize a Python script to automatically retrieve and load hourly public transportation data for Istanbul into a pandas DataFrame. The script sends an HTTP request to the specified URL to download a CSV file containing the transportation data.

	transition_date	transition_hour	transport_type_id	road_type	line	transfer_type	number_of_passage
0	2024-03-01	0	1	OTOYOL	CEVIZLIBAG-4.LEVENT	Normal	10
1	2024-03-01	0	1	OTOYOL	GULTEPE - SISLI	Normal	3
2	2024-03-01	0	2	RAYLI	KABATAS-BAGCILAR	Aktarma	14
3	2024-03-01	0	2	RAYLI	YENIKAPI - HACIOSMAN	Normal	23
4	2024-03-01	0	1	OTOYOL	KADIKOY-YENIDOGAN	Normal	4
...	...	...	...	...	...	...	...
2165359	2024-03-31	11	1	OTOYOL	KARTAL - KAYNARCA - VELIBABA MAH.	Normal	1
2165360	2024-03-31	11	1	OTOYOL	KARTAL - KAYNARCA - VELIBABA MAH.	Normal	1
2165361	2024-03-31	11	1	OTOYOL	KARTAL - KAYNARCA - VELIBABA MAH.	Normal	2
2165362	2024-03-31	11	1	OTOYOL	KARTAL - KAYNARCA - VELIBABA MAH.	Normal	3
2165363	2024-03-31	11	1	OTOYOL	KARTAL - KAYNARCA - VELIBABA MAH.	Normal	5

[2165364 rows x 12 columns]

Fig. 1. Raw Data

We dropped the some columns from the DataFrame. These columns were excluded because they did not contribute to the analysis focused on optimizing the timing and efficiency of Istanbul's public transportation system by improving the schedule and effectiveness of Istanbul's public transit system.

	transition_date	transition_hour	transport_type_id	road_type	number_of_passenger	town	line_name
0	2024-03-01	0	1	OTOYOL	10	BAKIRKOY	500L
1	2024-03-01	0	1	OTOYOL	3	BAKIRKOY	65G
2	2024-03-01	0	2	RAYLI	14	FATIH	T1
3	2024-03-01	0	2	RAYLI	23	SISLI	M2
4	2024-03-01	0	1	OTOYOL	4	ATASEHIR	14
...	...	...	...	...	...	...	...
2165359	2024-03-31	11	1	OTOYOL	1	ATASEHIR	132V
2165360	2024-03-31	11	1	OTOYOL	1	ATASEHIR	132V
2165361	2024-03-31	11	1	OTOYOL	2	ATASEHIR	132V
2165362	2024-03-31	11	1	OTOYOL	3	ATASEHIR	132V
2165363	2024-03-31	11	1	OTOYOL	5	ATASEHIR	132V

[2165364 rows x 7 columns]

Fig. 2. Filtered Data

We converted certain columns to datetime objects because this would make it easier to perform analysis. Additionally, we introduced a new column, categorizing each date into a day of the week. This transformation is crucial for analyzing patterns in public transportation usage across different days, enabling us to identify and optimize for peak and off-peak times.

	transition_date	transition_hour	transport_type_id	road_type	number_of_passenger	town	line_name	day_of_week
0	2024-03-01	0	1	OTOYOL	10	BAKIRKOY	500L	4
1	2024-03-01	0	1	OTOYOL	3	BAKIRKOY	65G	4
2	2024-03-01	0	2	RAYLI	14	FATIH	T1	4
3	2024-03-01	0	2	RAYLI	23	SISLI	M2	4
4	2024-03-01	0	1	OTOYOL	4	ATASEHIR	14	4
...	...	...	...	...	...	...	...	...
2165359	2024-03-31	11	1	OTOYOL	1	ATASEHIR	132V	6
2165360	2024-03-31	11	1	OTOYOL	1	ATASEHIR	132V	6
2165361	2024-03-31	11	1	OTOYOL	2	ATASEHIR	132V	6
2165362	2024-03-31	11	1	OTOYOL	3	ATASEHIR	132V	6
2165363	2024-03-31	11	1	OTOYOL	5	ATASEHIR	132V	6

[2165364 rows x 8 columns]

Fig. 3. Filtered Data

For the purpose of our project, which focuses on optimizing traffic flow specifically within the "RAYLI" (rail) and "OTOYOL" (road) segments of Istanbul's transportation system, we refined our dataset to include only relevant data.

	transition_date	transition_hour	transport_type_id	road_type	number_of_passenger	town	line_name	day_of_week
2	2024-03-01	0	2	RAYLI	14	FATIH	T1	4
3	2024-03-01	0	2	RAYLI	23	SISLI	M2	4
7	2024-03-01	0	2	RAYLI	11	KARTAL	M4	4
11	2024-03-01	0	2	RAYLI	9	GAZIOSMANPASA	T4	4
16	2024-03-01	0	2	RAYLI	3	BASAKSEHIR	M3	4

	transition_date	transition_hour	transport_type_id	road_type	number_of_passenger	town	line_name	day_of_week
0	2024-03-01	0	1	OTOYOL	10	BAKIRKOY	500L	4
1	2024-03-01	0	1	OTOYOL	3	BAKIRKOY	65G	4
4	2024-03-01	0	1	OTOYOL	4	ATASEHIR	14	4
5	2024-03-01	0	1	OTOYOL	5	BAKIRKOY	336G	4
6	2024-03-01	0	1	OTOYOL	1	BAKIRKOY	16KH	4

Fig. 4. Filtered Data

IV. ALGORITHMS

In our project, we implemented Genetic Algorithm, Particle Swarm Optimization and Simulated Annealing to optimize the scheduling of Istanbul's public transportation systems, specifically focusing on the RAYLI (rail) and OTOYOL (road) systems.

A. Genetic Algorithms

The objective of using the Genetic Algorithm was to determine the best hours of operation to minimize overcrowding and enhance overall efficiency. This aligns with our goal to improve passenger experience by reducing wait times and congestion during peak hours.

The Genetic Algorithm works by simulating a process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring of the next generation. For our specific application, each individual in the population represents a potential schedule for a 24-hour day, encoded as a series of integers (hours of the day).

The "fitness" of each schedule is evaluated based on its ability to minimize the total number of passengers during the selected hours, thus reducing congestion. The fitness function used is inversely proportional to the total number of passengers traveling during those hours, calculated as $\text{Fitness} = \frac{1}{\text{Total Passengers}+1}$. This formulation ensures that schedules with fewer passengers receive a higher fitness score, guiding the algorithm towards less crowded commuting hours.

Throughout the generations, the algorithm performs operations of crossover (to mix schedules from two parents to produce new schedules) and mutation (to randomly alter a schedule to explore new possibilities), leading the evolution of schedules towards optimal solutions.

B. Particle Swarm Optimization

Particle Swarm Optimization is inspired by the social behavior observed in flocks of birds or schools of fish. In this context, each "particle" represents a potential solution, which in our case is a possible schedule of 24 hours for the public transportation system. Each particle has a position that signifies a specific hour configuration and a velocity that directs its movement through the solution space.

The fitness of each particle is evaluated by its ability to minimize the total number of passengers during the hours it represents. This is computed using the fitness function $\text{Fitness} = \frac{1}{\text{Total Passengers}+1}$, where a lower number of passengers results in a higher fitness score. This formulation directly links to our project's aim of decreasing overcrowding.

During the optimization process, particles adjust their positions based on their own best known position and the best known positions of other particles in the swarm. This adjustment is influenced by the particle's velocity, which dynamically changes based on the relative success of its own and its neighbors' positions. This collaborative aspect of Particle Swarm Optimization enables the swarm to converge on the best solutions quickly and effectively.

C. Simulated Annealing

Simulated Annealing is a probabilistic technique for approximating the global optimum of a given function. It is analogous to the process of physical annealing with solids, where a crystalline structure is heated and then allowed to cool slowly until it reaches its most stable configuration. The algorithm transitions between solutions, not just to those that improve the solution but also to those that may initially seem worse, allowing it to escape local minima and move towards the global optimum over time.

The fitness function of each schedule is determined by the inverse of the total number of passengers traveling during those hours, calculated as:

$$\text{Fitness} = \frac{1}{\text{Total Passengers} + 1}$$

This formulation ensures that schedules with fewer passengers are considered more optimal, aiming to reduce overall congestion like the other algorithms that we used.

Acceptance Probability function determines whether a new solution should be accepted over the current one. It is defined as:

$$P(\text{accept}) = \begin{cases} 1 & \text{if new fitness} < \text{current fitness} \\ e^{\frac{\text{current fitness} - \text{new fitness}}{\text{temperature}}} & \text{otherwise} \end{cases}$$

This allows the algorithm to potentially accept worse solutions to avoid being stuck in local optima, with a higher likelihood of accepting worse solutions at higher temperatures.

The temperature in Simulated Annealing controls the probability of accepting worse solutions as the algorithm progresses, and it decreases according to the cooling rate. This gradual reduction in temperature helps the system stabilize towards the global optimum.

By applying these algorithms separately to data filtered for each day of the week and each road type, we can pinpoint the best three hours each day where traffic is lightest, thereby recommending optimal operational hours. This targeted approach allows us to dynamically adjust schedules to meet the demands of commuters, aiming to enhance the functionality and user satisfaction of Istanbul's transportation system.

V. EXPERIMENTAL RESULTS

The plots below visually compares the outcomes of three different optimization algorithms—Genetic Algorithm, Particle Swarm Optimization, and Simulated Annealing—used in our project to determine the least congested hour of operation for each day of the week within the 'RAYLI' and 'OTOYOL' environments of Istanbul's public transportation system. Each line on the graph represents the best hour suggested by each algorithm for minimizing congestion on a given day. By analyzing these trends, we can evaluate the consistency of each method in achieving the objective of reducing passenger congestion during peak hours.

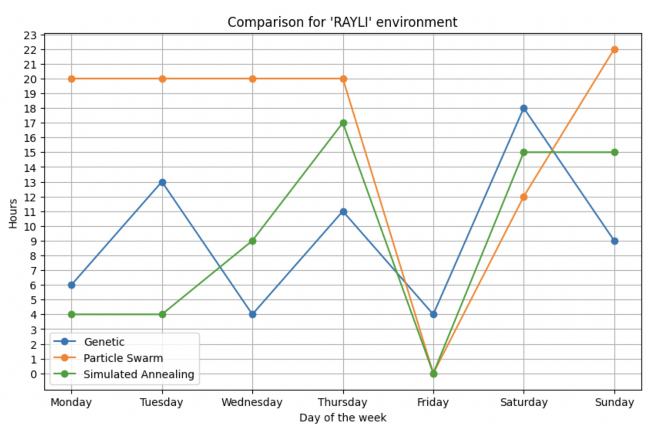

Fig. 5. Comparison for "RAYLI" Systems

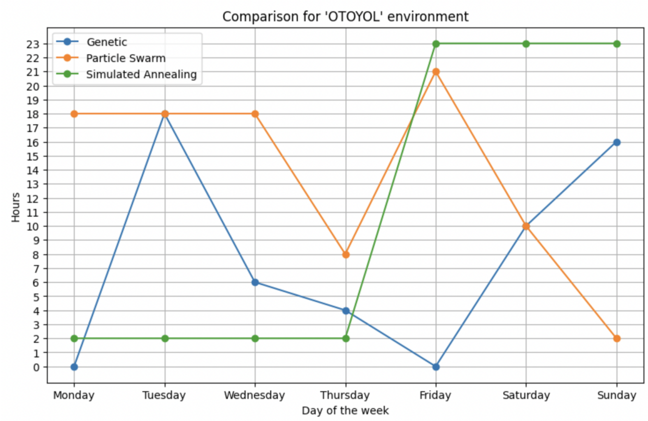

Fig. 6. Comparison for "OTOYOL" Systems

This set of plots below provides a comparison of the average best, medium, and worst hourly rankings for each day of the week, divided into two categories: RAYLI and OTOYOL systems of Istanbul's public transportation network. Each bar represents the mean of the rankings obtained from three optimization algorithms illustrating the variability in congestion levels at different times of the day.

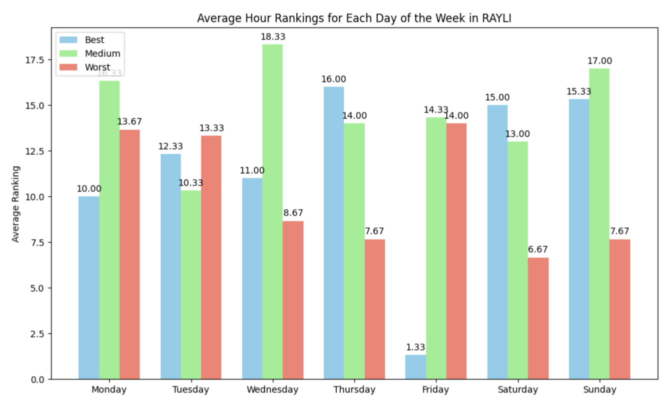

Fig. 7. Average Hour Rankings for Each Day of the Week for RAYLI

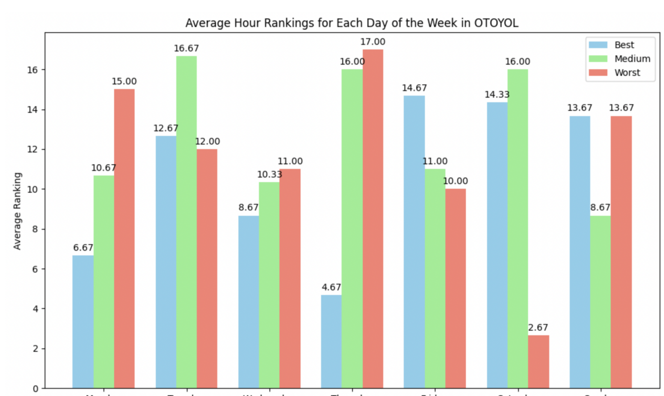

Fig. 8. Average Hour Rankings for Each Day of the Week for OTOYOL

VI. REAL-WORLD APPLICATION

The real-world implementation of our project, which focuses on optimizing the flow of human traffic in Istanbul's public transportation system, aims to increase livability in the metropolis. By implementing optimization algorithms such as Genetic Algorithms, Particle Swarm Optimization, and Simulated Annealing we are able to analyze and enhance scheduling and routing practices to effectively reduce overcrowding, minimize waiting periods, and optimize boarding procedures during peak hours.

The direct application of these techniques enables the identification of less congested travel hours and more efficient route allocations. This not only facilitates a smoother commuting experience for the city's residents but also supports the infrastructure to manage higher volumes of commuters without additional stress. As a result, the public transportation system becomes more capable of handling the daily flow of passengers, particularly during rush hours, thereby increasing its overall efficiency.

Furthermore, the optimized scheduling and routing strategies help in minimizing delays and maximizing the use of available resources. This leads to reduced fuel consumption and lower emissions, contributing to environmental sustainability and promoting a healthier environment. The implementation of these strategies also aids in enhancing public safety by reducing the likelihood of accidents and the spread of diseases in overcrowded conditions.

Additionally, IBB can use the findings from this project to specifically address and optimize traffic congestion during rush hours. By applying the optimized schedules and routing strategies developed through our research, IBB can more effectively manage the flow of passengers in the RAYLI and OTOYOL systems during peak traffic times. This optimization not only helps in decreasing congestion but also allows for the strategic addition of new departures where they are most needed, based on the predictive analytics provided by our optimization models.

VII. CONCLUSION

In conclusion, this project has demonstrated the potential of using advanced optimization algorithms—Genetic Algorithms, Particle Swarm Optimization, and Simulated Annealing—to enhance the scheduling and routing efficiency of Istanbul's public transportation systems, specifically within the RAYLI and OTOYOL networks. Through detailed analysis and optimization, we identified key strategies to reduce congestion, optimize service hours, and improve overall system efficiency, especially during peak rush hours. The implementation of these strategies not only promises a more efficient and reliable transportation network but also contributes to greater environmental sustainability, public health, and urban livability. As Istanbul continues to grow and face complex urban challenges, the insights and methodologies developed through this project offer valuable tools for city planners and policymakers. By adopting these optimized transportation models, Istanbul can continue to advance towards a more sustainable and inclusive urban future.

REFERENCES

[1] https://ulasav.csb.gov.tr/dataset/34-hourly-public-transport-data-set/resource/a5d64079-7cda-4bbb-859f-d0b99899d368

[2] https://colab.research.google.com/drive/1xTpMiqbr6_f7srtor6b4dGj86xxTaBZA?usp=sharing

[3] https://github.com/ahmedfgad/GeneticAlgorithmPython/tree/master/Tutorial%20Project

[4] https://doi.org/10.28991/cej-03091149

[5] https://github.com/rameziophobia/Travelling_Salesman_Optimization