Modelling, Simulation, and Optimisation of We-Doo's Parcel Delivery Runs.

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***Abstract*— The new logistics startup 'We Doo' is revolutionizing delivery services in suburban areas by introducing a business model that involves package drop-off at distribution points during the day and evening deliveries to customers on electric cargo bikes. This document provides an analysis of the proposed business model using simulations to validate the model and provide recommendations for which range of cargo bikes should be used in the trial phase. Through the simulation of scenarios, we examine how factors such as the number of parcels per customer and the size of the cargo bike range influence important parameters such as the daily tour length, working time, remaining parcels, and delays. By examining these metrics, we can provide insights into which ranges of cargo bikes are the most suitable for achieving a balance between efficient delivery and quality service. Ultimately, our analysis will help 'We-Doo' to make informed decisions as the landscape for suburban delivery services continues to evolve.**

Keywords— ***Simulation, Multiple simulations, Cargo bike Optimization.***

I. INTRODUCTION

A. Motivation and Background

The last-mile delivery service in commuter townships has changed a lot with the rise of cities and e-commerce. This research introduces a new approach that involves dropping off packages during the day and doing eco-friendly deliveries in the evening using electric cargo bikes. We Doo is a startup that wants to change the delivery system by collecting packages, dropping them off at distribution points, and then having drivers on electric bikes do the deliveries in the evening. But it's important to look at how it works and make sure it's practical and efficient. Simulation-driven analysis can help bridge the gap between the vision and how it's actually done, which will help We Doo succeed and change how deliveries are done in commuter townships!

B. Problem Statement

The challenge lies in testing and improving the efficiency of the delivery service model proposed by We-Doo. This model involves collecting packages in the daytime and delivering them to commuter townships on electric bikes. To assess the effectiveness of this delivery approach in various conditions, with varying average parcel quantities and cargo bike ranges, we must consider factors such as the duration of each day tour, the time it takes to complete the task if any leftovers are present, and the time it takes for an individual to reach the destination. The simulation results must be used to recommend the most suitable cargo bike range in order to ensure efficient delivery and satisfactory service. The objective is to assess the effectiveness of the delivery approach and then determine the most effective way to deliver We-Do to these townships. A problem statement is provided below:

- Since the average number of parcels received per day by a customer is not known at this time, you must report for a certain number of values within the expected range of 0.2 – 0.3, but you can also report for values outside of this range. You can decide how many and what values you want to investigate. Select at least 3.
- In order to make an informed decision regarding the selection of a cargo bike, it is necessary to analyze the performance of the chosen p with different p ranges (30 km, 35 km, 40 km, and 45 km) and to substantiate the recommendation for the chosen cargo bike.

II. LITERATURE REVIEW

Simulation is important when it comes to testing out new delivery models and seeing if they work. It's a great way for people to try out different things, figure out what works best, and make decisions. Scientists have used simulation to look at different parts of delivery systems like route optimization [1], how to allocate resources, and how to measure performance. In the study conducted in [2], authors developed a simulation model to examine the dynamic growth of deliveries in an urban area. Additionally, scholastic models were proposed which have multiple stages and employ Monte Carlo simulation and the heuristic method for optimization. Another paper highlighted the disadvantage of the conventional method and proposed a model called parcel locker which significantly reduces the cost of last-mile deliveries.[3] The authors briefly discussed the advantages and disadvantages of parcel lockers versus home deliveries using multiple simulation models. The choice of cargo bikes has become one of the most important decisions in the design of last-mile efficient delivery systems[4]. Factors like cargo capacity and range affect the ability to fulfill delivery requests. Previous studies have shown that cargo bike characteristics play a significant role in determining delivery efficiency and customer experience[5]. In We-Doo's model, the choice of cargo bike range directly affects delivery capacity as well as performance metrics like tour duration and working time. Measuring performance metrics, including daily tour duration, working time, remaining parcels, and delay per parcel, is an essential part of assessing the feasibility of last-mile delivery models. Research has highlighted the importance of meeting delivery time constraints while maintaining delivery quality. Our findings concur with these findings, particularly in relation to the capacity limitations posed by cargo bike ranges, as well as the effect of working time on the reliability of service.

III. METHODOLOGY

In this project, we've used the methodology outlined below to carry out the simulation. The code is inspired by the material taught and suggested by Professor Christian Horn in the subject of Modelling, Simulation, and Optimization. We've implemented the simulation model using Python language in the jupyter notebook. We've also used Google Colab at one point for the quick execution of code. We start off by creating a development base model and using its visualizations to get a better understanding of the situation. The baseline model-building process was initially based on a 30 km wide range bike with a constant speed, followed by the inclusion of additional range vehicles. Subsequently, additional parameters such as working time, width, and parcel leftover, can significantly alter the results and enhance the simulation model's performance. The basic model-building process is outlined below:

A. Data Collection

The first step is to acquire the necessary information for the simulation. The map of the township containing the distribution point and the customer locations must be acquired. The parameters related to the customer parcel reception rate (p) and the cargo bike range (r) must also be acquired. The data.pickled. file must be loaded in order to access the data..

B. Simulation Setup

Create a simulation model in your program. Specify things like the size of the cargo bike range, how long it takes to work (3 hours), the average speed (15 km/h), how long it takes for a call to be answered (40 seconds), how long it took for a handover (10 seconds per parcel), how much time it takes to prepare each parcel (50 seconds), and how long it took to complete a day-end procedure (10 minutes). Set up variables for tracking metrics like the daily tour length, the working time, how many parcels are left, and how long each parcel takes to process.

C. Bike Selection

We'll be running the simulation for each cargo bike (r) with a range of 30 km, 35 km, 40 km, and 45 km. This way, we can see how the different cargo bike ranges affect the delivery performance under different conditions.

D. Parcel Generation

Generate parcels for each customer using an exponential distribution using the calculated average time (1 /p). Interarrival time is based on the anticipated daily parcel arrival.

E. Route Planning

The parcels will be categorized, and the routing of the cargo bike will follow the algorithm of the shortest path, taking into account the distance between the customer's location and the point of distribution.

F. Results

This step includes the collection and compilation of simulation model data and statistics. Various experiments performed with different parameters may produce different results. In this study, the data was collected for the Baseline model and the Multi-Simulation model.

IV. SIMULATION MODEL

The simulation is implemented in Python using an Object-Oriented programming methodology. The code contains various classes that refer to various modules or components of the simulation model. Each class also contains functions and generators that are defined within the simulation model. Data manipulation was done with Pandas, calculations were made with NumPy, plotting of the graph generated by the simulation model was done with Matplotlib, and simulations were executed with Simpy. The steps associated with the simulation model are outlined below.

1) Map and data generation

A map is generated by using different functions like points and distance, lines, triangles, triangulation, etc. Here 7321 value is used for the seed value to generate the data. To test the application, use seed=0. This will generate a very small map, with very few customer locations, and a very small collection of delivery data. To generate the correct simulation data, use your student ID's last four digits as the seed value as shown in figure 1.

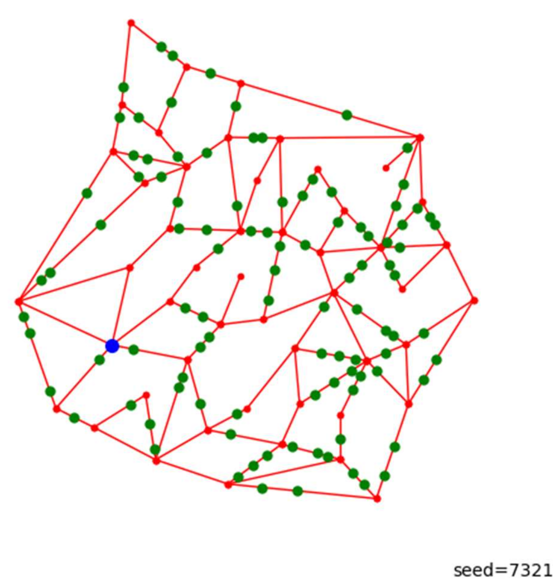

Fig 1: Map

2) Shortest Path find

Here 2 algorithms are used to find the shortest distance fig. 2 i.e. A* Algorithm and Floyd-Warshall Algorithm. An A-star is a search algorithm that finds the shortest path between the start and endpoints. It is a useful algorithm that is commonly used in map traversal to determine the shortest path to take. A* was originally developed for graph traversal problems to construct a robot that could find its own path.

Floyd-Warshall is a dynamic programmatic algorithm designed to find the shortest path in a weighted graph with negative weight cycles. It works by calculating the shortest direction between each pair of vertices in the graph and using a matrix of intermediary vertices to maintain the music of the previously recognized route.

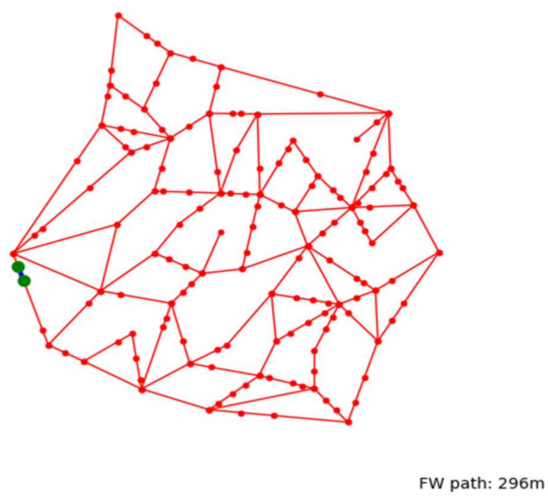

Fig.2

3) Roundtrip

Creating the roundtrip using iterative integer programming and pulp library are used. The heuristic method is as well used to simulate the round trip shown in fig 3. When we are dealing with complex problems, heuristics are a great way to find solutions quickly and efficiently. They're not always guaranteed to give you the best or most effective answer, but they usually do within a reasonable amount of time.

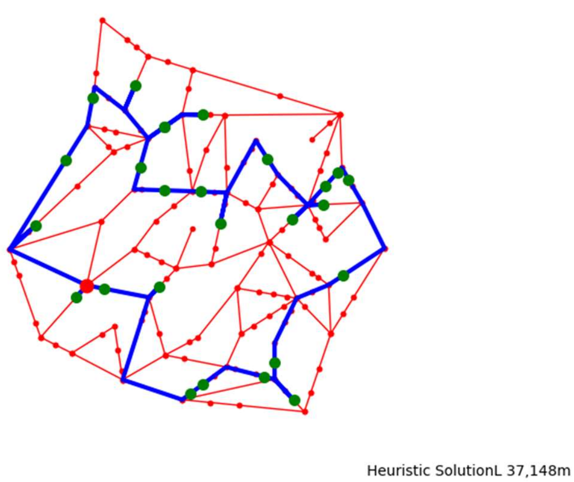

fig. 3 Round Trip

4) Model

Four different models are implemented in this code. i.e. parcel, customer, driver, and delivery center. Parcel class follows a cycle of processing, in transit (from manufacturing to distribution center), arrival in the distribution center, ready for delivery, out for delivery, customer not present, returned to the distribution center, and delivered. The customer is passive. The probability of the customer being at home is q, and the time to open the door is expovariated. If the customer does not open the door within a specified time, the package is sent back to the fulfillment center.

5) Run Simulation

To run the simulation cumulative preparation time, process returned parcels, and the average customer time to answer the door, accept a parcel, or sign off are predefined. After that, we used the function simulation and verified the model. Run a small simulation on data.pickled file and by changing the arguments, we tried to optimize the code. In the end, we run multiple simulations to achieve the goal by changing the limit and p-value.

V. RESULTS

A detailed simulation was conducted to assess the performance of the We-Doo Evening Delivery Service in the commuter townships based on the chosen values of Average daily parcels per customer (p) and Each cargo bike range (r). Here we have taken five p values e.g., 0.20, 0.21, 0.22, 0.25, 0.30. Here, working time is a soft constraint; the value should be around 180 min. Daily tour length and leftover parcels are hard constraints. Key findings and evaluations for each metric are presented below:

A. p=0.20:

When p is 0.02 and the range is 30 km we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 29786.52, 175.91, and 41.41 respectively. While the range is 35 km we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 34719.12, 198.59, and 27.94 respectively.at 40 km range we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 39340.13, 218.32, and 16.64 respectively. the range is 45 km we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 42563.64, 232.78, and 11.61 respectively. For the p-value 0.02, the best model is the 35 km range as shown in the below fig 4-6.

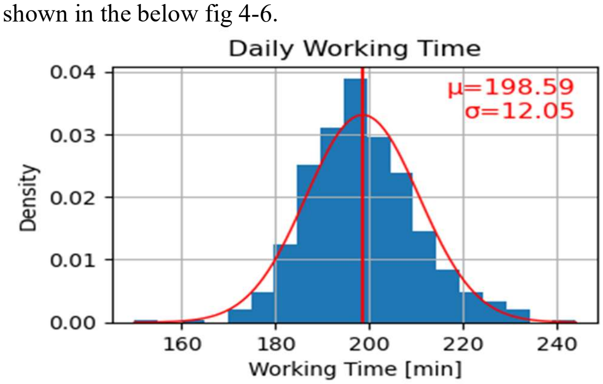

Fig 4

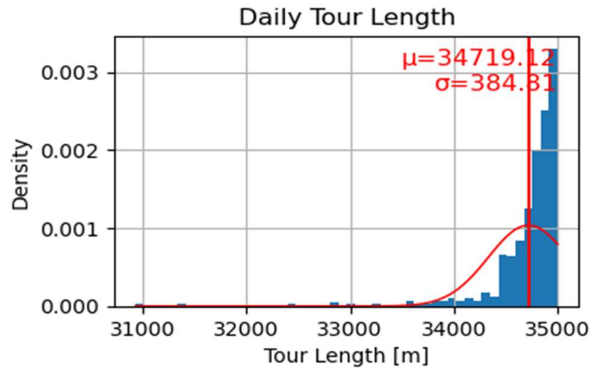

Fig 5

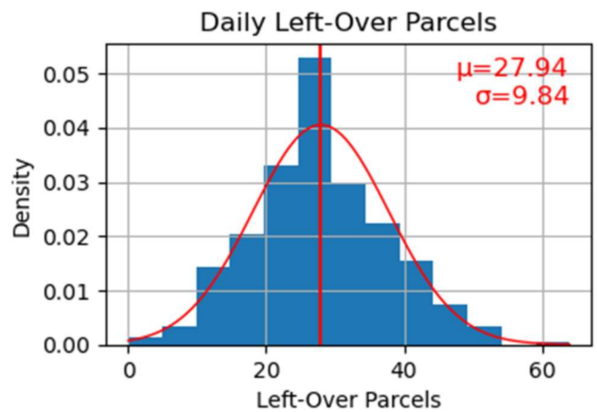

Fig. 6

B. p=0.21

when p is 0.21 and the range is 30 km we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 29797.48, 178.24, and 45.48 respectively. When a 35 km bike is used the avg. daily tour length, daily working time, and the number of leftover parcels are 34735.42, 201.17, and 29.99 respectively. For a 40 km bike, we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 39422.00, 221.55, and 19.5 respectively. When it comes to the 45 km range we achieve the avg. daily tour length, daily working time, and the number of leftover parcels are 42961.09, 237.46, and 12.73 respectively. Here we can choose a 35 km range cargo bike Portrait in the below fig.

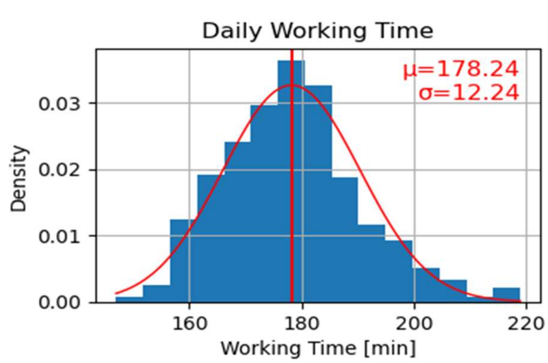

Fig 7

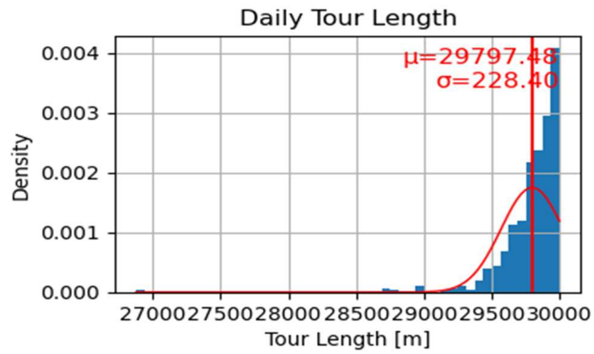

Fig 8

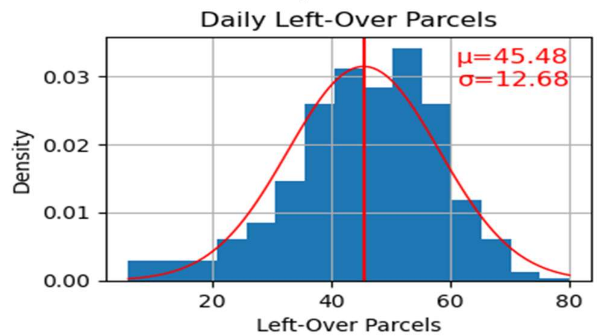

Fig 9

C. p=0.22:

For the 30km range of the cargo bike, the working hours is 180.51 minutes, the distance is 435.33 meters, and the parcel leftover is 15.47. For the 35km range, the hours for working are 168.51 minutes, 298.18 meters is the average distance and a leftover parcel is 49.56. For the 40km range, the values are shown in Fig.. For the 45km range, the average working time is 242.57 minutes, and the parcel leftover 14.47.

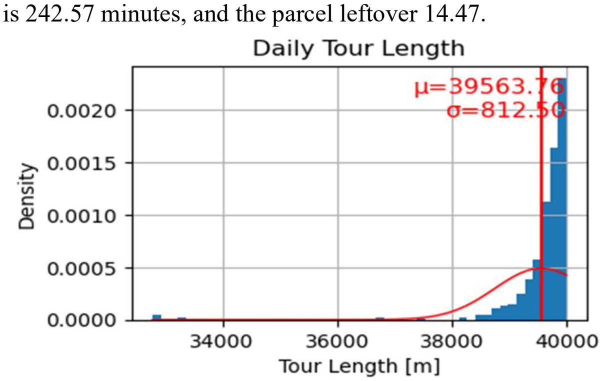

Fig. 10

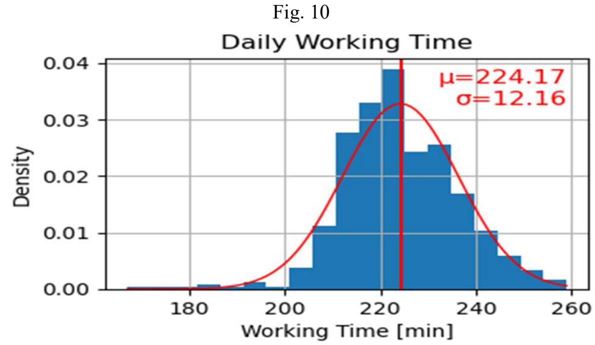

Fig 11

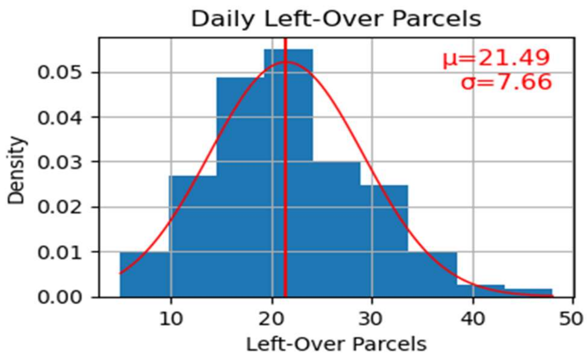

Fig 12

D. p=0.25:

The average working time of a cargo bike with a range of 30km is 187.26 minutes. The number of remaining parcels is calculated to be 60.41. The average distance is calculated to be 29825.73 kilometers. The same parameter is analyzed for a bicycle with a range of 35km, which is displayed in Figure 13-15. The average working time for 40km is 231.53 minutes, and the values for 40km are 39709.18 and 28.78 respectively. For 45km, the average working time is 252.65 minutes, the range is 44289.04 meters and the values for 45km are 14.10 and 18.87 respectively.

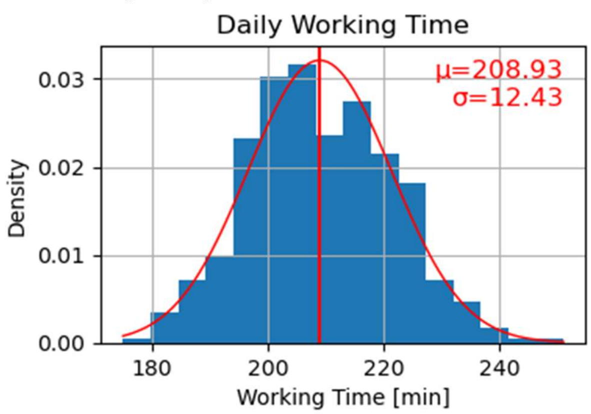

Fig. 13

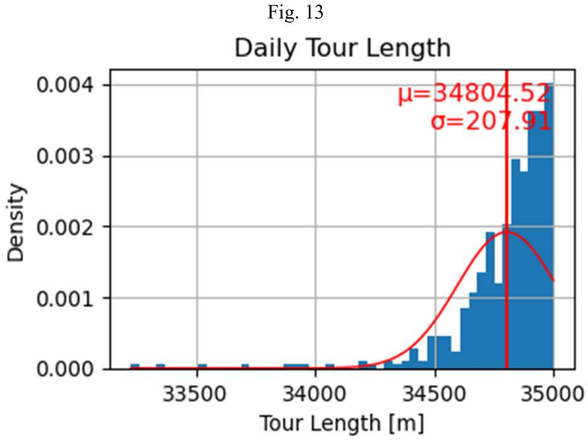

Fig 14

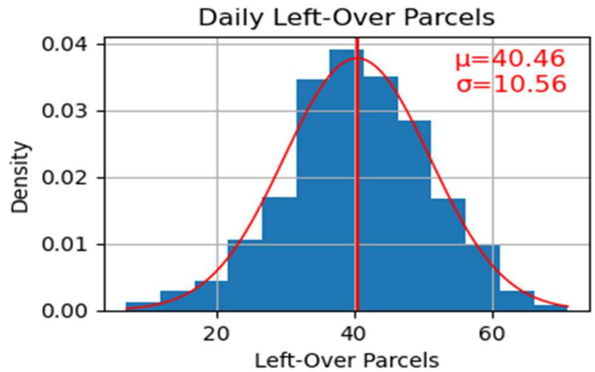

Fig. 15

E. p=0.30:

The average working time of a cargo bike with a range of 30km is 195.41 minutes. The number of remaining parcels is calculated to be 74.45. The average distance is calculated to be 29839.24 kilometers. The average working time for 35km is 220.02 minutes, and the values for 35km are 34822.72 and 56.30 respectively. For 40km, the average working time is 242.00 minutes, the range is 39766.79 meters. The same parameter is analyzed for a bicycle with a range of 45km, which is displayed in Figure 16-18.

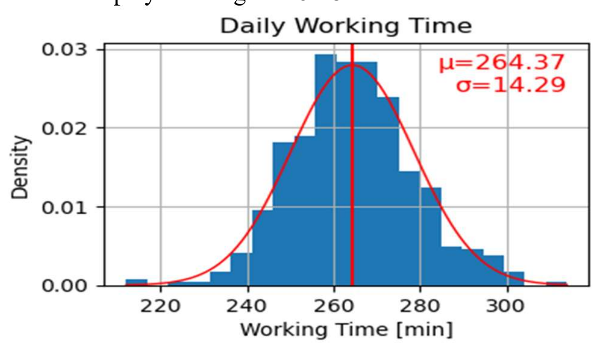

Fig. 16

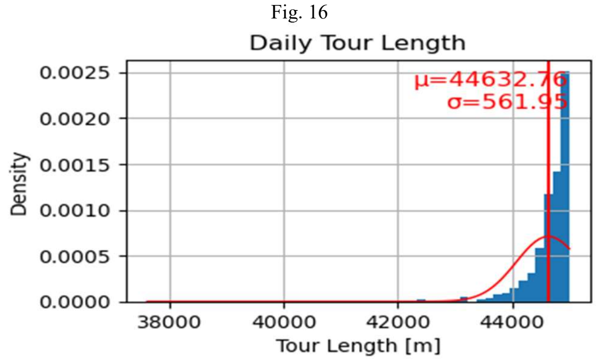

Fig. 17

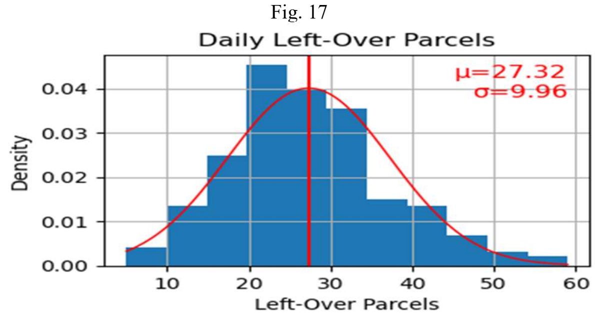

Fig. 18

VI. EVALUTION

On the basis of the generated results, it can be concluded that the best-fit models were obtained with a p-value of 0.20 and 0.21 respectively. The generated data suggests that the greater the p-value, the poorer the model's performance. Bike range and parcel delay are inversely professional. The best fit according to the paper can be determined by the delay of the parcel, as illustrated in Figures 19-23.

Delivery Delay	p=0.2 30km bike range	p=0.2 35km bike range	p=0.2 40km bike range	p=0.2 45km bike range
None	21.70%	27.70%	46.30%	61.20%
1 days	24.40%	40.00%	36.30%	27.00%
2 days	26.50%	15.60%	11.20%	8.00%
3 days	10.00%	8.80%	4.20%	2.70%
4 days	6.50%	3.90%	1.30%	0.80%
5 days	5.20%	2.20%	0.50%	0.30%
6 days	2.30%	1.00%	0.30%	0.10%
7 days	1.30%	0.50%	0.00%	0.00%
8 days	1.00%	0.20%		

Fig 19

Delivery Delay	p=0.21 30km bike range	p=0.21 35km bike range	p=0.21 40km bike range	p=0.21 45km bike range
None	21.00%	27.50%	42.20%	60.10%
1 days	23.20%	40.10%	38.50%	27.30%
2 days	26.50%	15.50%	11.60%	8.70%
3 days	11.20%	8.70%	5.10%	2.70%
4 days	6.00%	3.80%	1.60%	0.70%
5 days	5.40%	2.20%	0.70%	0.20%
6 days	2.30%	1.10%	0.20%	0.10%
7 days	1.80%	0.60%	0.10%	0.00%
8 days	1.10%	0.20%	0.00%	
9 days	0.60%	0.10%		

Fig 20

Delivery Delay	p=0.22 30km bike range	p=0.22 35km bike range	p=0.22 40km bike range	p=0.22 45km bike range
None	20.60%	27.20%	38.50%	
1 days	21.80%	37.30%	40.90%	
2 days	26.40%	16.90%	12.30%	
3 days	11.70%	9.40%	5.10%	
4 days	6.30%	4.60%	2.00%	
5 days	5.40%	2.20%	0.90%	
6 days	3.00%	1.10%	0.20%	
7 days	1.90%	0.60%	0.10%	
8 days	1.10%	0.40%	0.00%	
9 days	0.80%	0.20%		
10 days	0.30%	0.10%		
11 days	0.20%			

Fig 21

Delivery Delay	p=0.25 30km bike range	p=0.25 35km bike range	p=0.25 40km bike range	p=0.25 45km bike range
None	19.90%	25.70%	33.50%	51.10%
1 days	20.90%	34.60%	42.10%	33.20%
2 days	24.80%	19.90%	12.50%	10.10%
3 days	13.50%	8.80%	7.20%	3.80%
4 days	6.50%	5.10%	2.60%	1.40%
5 days	5.20%	2.80%	1.20%	0.40%
6 days	3.60%	1.50%	0.50%	0.10%
7 days	2.00%	0.80%	0.30%	0.00%
8 days	1.30%	0.40%	0.10%	
9 days	0.80%	0.20%	0.00%	
10 days	0.40%	0.10%		
11 days	0.40%	0.10%		
12 days	0.30%	0.00%		

Fig 22

Delivery Delay	p=0.30 30km bike range	p=0.30 35km bike range	p=0.30 40km bike range	p=0.30 45km bike range
None	20.30%	24.10%	30.10%	42.40%
1 days	20.10%	27.70%	41.10%	38.30%
2 days	21.70%	24.80%	13.20%	12.10%
3 days	15.90%	8.50%	8.70%	4.70%
4 days	6.20%	6.50%	3.40%	1.60%
5 days	5.80%	3.80%	2.00%	0.50%
6 days	3.70%	1.90%	0.70%	0.20%
7 days	2.10%	1.10%	0.40%	0.10%
8 days	1.40%	0.70%	0.20%	
9 days	0.90%	0.30%	0.10%	
10 days	0.70%	0.30%	0.10%	
11 days	0.40%	0.10%	0.00%	
12 days	0.20%	0.10%		
13 days	0.10%	0.00%		

Fig 23.

VII. CONCLUSION

The primary objective of this study was to assess the models derived from simulations and multiple simulations conducted on them. Comparing the values generated for the various ranges of the cargo bikes, it can be observed that, as the p-value of the range of parcels increased, there was a significant increase in the average working time as well as the value of the remaining parcels and delays. Furthermore, the distance parameter did not significantly influence the results. The average time of the cargo bikes increased with their range, however, the number of remaining parcels and delays significantly decreased. When evaluated based on the average time, electric cargo bikes with a p-value of 0.2, 0.21, and 0.23 are the most suitable, however, when evaluated based on the remaining parcel and delays, the cargo bike with a range of 40km or 45km is the most suitable in the same data.

VIII. FUTURE WORK

In future research, the simulation model can be further refined to support better decision-making for the delivery of 'We-Do' township services. For example, dynamic modifications can be made to cargo bike routes based on customer density data to improve delivery efficiency. Sophisticated vehicle routing algorithms optimize tour planning by taking into account constraints like time limits or vehicle range.

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