Modelling, Simulation and Optimisation CA

1st Steven Travers - X23299525
NCIRL Modelling, Simulation & Optimisation CA
Postgraduate Diploma in Science in Data Analytics (PGDDA)

***Abstract*—This project aims to use various modelling and simulation techniques to**

***Index Terms*—Traffic Modelling, Forecasting**

I. Introduction

A. We-Doo & Problem description

'We-Doo' is a start up company that operates a parcel delivery service to a local area. In recent months, there has been rapid expansion. This has led to the decision for the company to change its model and introduce a new warehouse for local areas. This new model is being piloted with one town. We-Doo have allocated a budget for this expansion project and the aim of this discussion is to identify which warehouse location, from a selection of 5 locations, is best placed to minimise costs and maximise efficiency for this expansion. To do this, simulations will be ran on several different model ideas to try to identify the warehouse location, and model, is best suited for the expansion plans.

II. Literature Review

Modelling and simulation techniques are used extensively throughout the world and to help to identify different models that may be used for this project, there were some external sources used.

A. Delivery Companies

Brief discussions with local delivery drivers for DPD & Amazon were had to try to understand their current model and potential areas to reduce bottlenecks in their workflow. There were some differences noted between these delivery companies. For example, with DPD, customers were contacted via email/phone the morning of their delivery with an ETA(estimated time of arrival). This is a multi purpose approach that benefits both the customer and the driver. Customers were benefit due to the fact that they now have a, in general, 2 hour slot for their delivery. They know to expect a knock on the door / phone call within that time. This then in turn benefits the driver as there is less of a wait for the driver to deliver the parcel. Amazons model differs slightly from this, with the Amazon app (and by email if required), a notification is sent when your parcel is out for delivery. Although there is not a specific time given, you have the option to track the delivery when the driver is several stops away. As before, this reduces the time the driver is waiting at the door for customer to answer.

B. Amazon Picture on Delivery

An area of interest which was identified is an Irish Times article that States that in 2019 just 7% of the Irish workforce usually worked from home. This has increased to 25% in 2022 [1]. The reason for highlighting this is, in the models produced for this project, it would be beneficial to show how the model compares with the scenario of reduced waiting time for driver at customer location. To do this, the idea of picture on delivery will be used. This was introduced by Amazon c2018, with the idea of the driver placing the delivery in a *secure* location and taking a picture of the delivery to send to customer. This is the basis of one of the models discussed below. The premise of this model is that the bottleneck for drivers waiting for the customer to answer the door is removed. The new model will show the driver placing the delivery, knocking on the door and taking a picture as they leave. This reduces the driver wait time significantly. It **MUST** be noted that we are not modelling for customer satisfaction and realistically this should be taken into account!

C. Derivation of test parameters

Due to the simplicity of the code, a variety of parameters can be tested very easily. One of the key parameters that will be tested is the change in P value.

III. Methodology

A. Code Generation

All code used, with some very slight adjustments noted below was generated during lectures. The main difference is the map used and the parameters fed into the model. The parameters, which will be discussed in their relevant sections, were derived from the literature review and also using guesstimates. Jupiter Notebooks was used so the code could be separated into the 3/4 different models tested.

B. Map Creation

1) Map Variants: There were 3 map variants generated for this project. They can be described by Table I where C & N represents the counts of customers and nodes.

Map	Seed	C & N
SimpleData	0	(5,20)
TestData	9525	(20,35)
ProjectData	9525	(100,35)

TABLE I
VARIOUS MAP DETAILS

SimpleData was used to very quickly test ideas and ensure code was running correctly. Since simulations and path-finding algorithms are very resource intensive, TestData was used with the final map configuration and reduced customer count to reduce the run time of some ideas to be used. The ProjectData was used to ensure statistical tests could be used to see how beneficial models were and if there was statistical significance between models. The graph for the Project data map including customers can be seen in Figure III-B1. Test and simple data can both be found in accompanying code but due to similarity of project and test data it is excluded from this report.

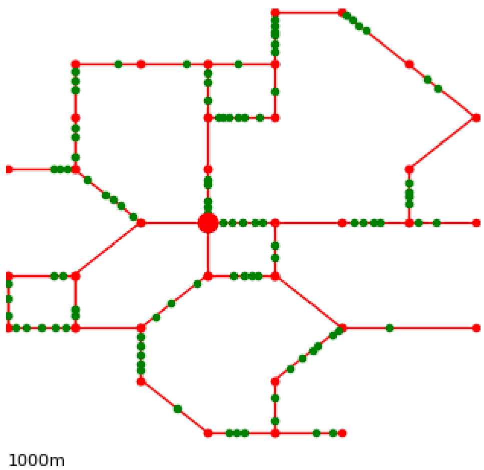

Fig. 1. Project Data map including customers and central warehouse

2) Candidate Warehouse Locations: The code provided generates a set of N candidate warehouses. For this project, 5 potential warehouse locations were considered. The list of options can be seen in Figure 2

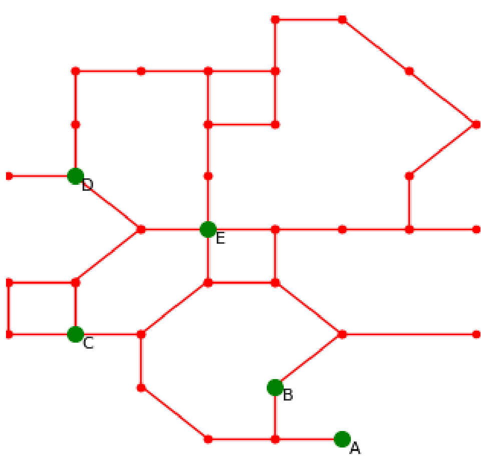

Fig. 2. Initial Candidate Warehouse Locations

Of the above warehouse locations and based off initial thoughts, it is assumed that warehouse in location E will be the cheapest. This hypothesis is based off the logic that this warehouse is the most central of all locations & in theory, should reach all customer locations in the smallest average distance. It must be noted that when testing with small sample size of customers, it is possible majority of customers are in the so called "Bottom Half" of the map. For this reason, to reduce the risk of this. It must be ensured the test data has some customers in the top half of the map / otherwise the customer count is large enough in the project data to ensure random locations.

C. Model 1 - Basic

The first model that will be tested is the standard model with no variations in the initial code. This is used for a benchmark for which to aim to improve on. This model uses the Chinese Postman Problem (CPP) to find the shortest delivery route for each day.

1) Model 1a - One Driver: Using the CPP code for the project data, given no distance constraint and only one driver, there was a feasible solution. However, with one driver, covering the whole map of 100 customers is extremely difficult. Once the 40km constraint was added to the CPP code, the solution was infeasible. For this reason, and looking at the map, a conclusion was made to stick to at least two drivers for this project.

2) Model 1b - Multiple Drivers: The new benchmark for this project will now be derived using the initial constraints in the code provided, with 2 drivers for CPP.

D. Model 2 - Picture on delivery

For the Picture on Delivery model, there were several parameters that needed to be updated in the code. The premise of this model is that the driver no longer stops to wait for the customer to come to the door after knocking as is the case with Fig. 3.

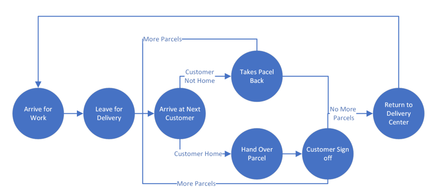

Fig. 3. Manually Created Event Graph for Delivery in Model 1

After knocking, the driver now takes a picture of the parcel in a secure location and leaves. This is a simplified model which drastically reduces driver wait time during deliveries. The event graph can be seen in Fig 4

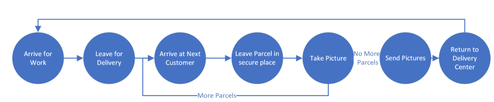

Fig. 4. Manually Created Streamlined Event Graph for Model 2

The following Parameters needed to be updated in order to run the simulation.

Parameter	Before	After
CUSTOMER_NOT_AT_HOME	10%	0%
AVE_TIME_ANSWER_DOOR	40	0
WAIT_TIME_IF_CUST_DOESNT_ANSWER_DOOR	50	0
AVG_HANDOVER_TIME	10	20
AVE_SIGN_OFF_TIME	10	0
DAY_END_PROCEDURE	600	1000

TABLE II
VARIOUS MAP DETAILS

With the simplified event graph for parcel delivery, the parameters in Table II required updating. Some parameters were set to zero as they are no longer required, while others were increased such as Day end, to allow for additional time to send pictures manually on days end. There are several expected outcomes from the updated simulation. Prior to running these simulations, they were noted. These outcomes include:

1) Delivery costs are reduced as driver bottleneck of waiting for customers is gone.
2) Route times are reduced for same reason.
3) Number of parcels left over per day should be significantly smaller. Potentially not Zero as there is still the 40km limit, thus making the system balanced.

E. model 3 - Deliveries at Night Time

The final model which will be tested during this project is the possibility of doing deliveries at evening/ night time. The idea of pictures taken still applies, so the event graph doesn't not change significantly, except the driver does not knock if its too late. The reason for this simulation is to try to identify what has more of an impact on the price per delivery, is it the drivers wage or the "Wasted" time they spend waiting around. The changes to the parameters for this simulation can be seen in Table III

Parameter	Before	After
Shift Allowance Factor	NA	1.3x
Max_Distance	40km	45km
AVE_SPEED	15kmh	17.5kmh

TABLE III
SIMULATION MODEL CHANGES

To try to make the model more realistic, a shift allowance factor was applied, this was set at 1.3x. This increased the drivers salary by 1.3x. Another brief test that was done was with the reduced wait times, speed increase and increased distance, was one driver now feasible. This test failed as Plan returned a nulltype. This is highlighted in the code.

IV. RESULTS AND INTERPRETATION

The initial hypothesis for this project when viewing the candidate warehouses is that the

After running simulations on the 4 models above, it can be concluded that the model which provides the lowest cost based on the information tested is the xx model.

A. A Caveat to Results

When explaining the results to *We-Doo*, it should be stressed that the above models mainly focus on reducing the cost. However, there should be many other factors taken into consideration for this project. An example is customer satisfaction. In the above models, the event of leaving a delivery at the door was tested. Although this is done in practice, there should be an option to exclude this from parcels say over a certain threshold. This reduces the possibility of theft

V. Reflections and Future Work

A. Reflections

Reflecting on this project, it was interesting to learn about several different route finding algorithms and how to implement them in python. Having the event graphs at the beginning helped to make understanding the code easier. Although the scope of this project is not completely code focused, with an increased ability in python, some of the possibilities to enhance this code, as will be discussed in Future work would have been possible.

One of the most interesting pieces of this project is the ability to change parameters in the code and see the impact that this has on working hours and costs. Slightly changing some parameters and rerunning the same code can give quite different results.

Reflecting on the possibility of including other parameters, a parameter that would have been interesting is a daily cost for the warehouse. An assumption that was made on this project were that all candidate warehouses are of equal cost. However, if we assume that the map generated using the seed is a town, it is very likely that a warehouse in the middle of the town will be far more expensive to rent than a warehouse on the outskirt. This would make selecting the relevant warehouse more complex.

B. Future Work

There are several possibilities for future work with this project, some of this includes adding more parameters to the code and testing several different models. An area that would be of potential benefit to *We-Doo* is trying to future proof these models. As mentioned in an article on CapitalOneShopping, "From 2017 to 2022, the number of packages the average American received in a year increased by 73 [2]. This is interesting as there would be merit in including some sort of forecasts of the value for the parameter P, the average number of parcels per day, based on these statistics. The growing presence of Amazon and websites such as Temu with cheap delivery it amplifying the growth of home deliveries throughout the world. It would be interesting to see what potential models parameters work best when the value for P increases significantly, which might help to plan for *We-Doo's* future. Another key parameter that would be worth future proofing is the max possible daily distance travelled. With improvements in Battery powered vehicles, how will this impact the parcel deliveries and costs with increased range. Another area to consider when future proofing is the change in cost of charging the bike and wages. How can *We-Doo* maximise the efficiency of the cargo bikes? Since the scope of this project was to minimise costs now, the above was not considered. However, future proofing these variables

Another area that could be explored with some more time to research is customer behaviour. In this project, the main focus was to minimise the cost for the client. Although in an article published by McKinsey, c30% of people would pay an increased delivery charge for faster delivery [3]. The remaining 70% are content with having the cheapest form of delivery [3]. Following on from this, it would be useful to have another option for customers of *We=Doo* for them to select their method of delivery. If they would like faster delivery these get prioritised daily. Due to the time constraints of this project, it was not possible to add such logic into the code. It would be interesting to test several models using the above information such as is there a benefit to hiring a driver purely for next day / faster deliveries? These could also take the parcels that were not delivered on the previous day too potentially.

With some further programming knowledge, it would be interesting to see if it is possible to find an optimal group of parameters that minimise the cost for deliveries. This could be done by implementing some further choice of parameters and utilising machine learning methods. This information could provide useful analysis to *We-Doo* such as if they reduce driver wait time by x%, this will lead to a reduction of €y per delivery. Another parameter worth looking at is the driver salary. The histogram plots in the code show that there are some days in which the drivers work less than 2 hours. This is sub-optimal as the minimum salary per day is based off 2 hours work. Although some of the models segregate the map into areas, how would this change if at first, the maps are segregated, but when a driver is finished their route, can they help the other driver?

The final piece that would be interesting to look at, and related to the machine learning aspect of this project is understanding how to best segregate the map. Due to time constraints, for this project, it was roughly split in half when using two drivers. It would be possible with some more time to implement a function that segregates the map depending on split of customers / distance covered, i.e. for 3 drivers the map is split so each driver has one third of the customers. Even better if this could be done daily & the sections can change slightly depending on daily routes.

These are all possible factors to take into consideration before providing a definitive solution to *We-doo*. Although the model that was agreed in the results section is the best model that was found, there is nearly a guarantee that there are better models to be found. This must be stressed to the client when providing the conclusion of this paper as small changes in some parameters may lead to a better more optimal solution.

References

[1] C. Gleeson, “Remote working: A quarter of ireland’s workers now operate from home most of the time,” Aug 2023. [Online]. Available: https://www.irishtimes.com/business/work/2023/08/08/ireland-adopting-hybrid-working-at-greatest-rate-in-eu/

[2] Feb 2024. [Online]. Available: https://capitaloneshopping.com/research/package-delivery-statistics/

[3] M. Joerss, F. Neuhaus, and J. Schrouml;der, “How customer demands are reshaping last-mile delivery,” Oct 2016. [Online]. Available: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/how-customer-demands-are-reshaping-last-mile-delivery