Truck Scheduling and Base Location for The Warehouse Group

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1 Abstract

The Warehouse Group are looking to determine a suitable truck logistics plan that minimizes transportation costs and given the current economic situation, they are also questioning whether closing the Northern distribution centre will be more cost-effective than having both Northern and Southern distribution centres open. The data provided by The Warehouse Group has been analysed and visualized to estimate the number of pallets required weekly and on Saturday's to meet demand. Using this, feasible trucking routes were generated, and the least-cost route schedules were decided using a mixed-integer program, which have been visualized. The results are as follows; if both Distribution centres were used the total routing cost would be $198,187.24 and if the North Distribution were to be closed the total routing cost would be $219,898.64. If the Northern Distribution centre were to be disbanded, our optimal solution suggests that the Warehouse Group would save $378,290 more per month during this period than keeping both Distribution centres open. This given that we saved $400,000 initially just by disbanding the North Distribution.

A simulation was conducted in order to take into account the variations in demand and sensibly approximate the effect of traffic. This resulted are as follows; if both distribution centres are used the 90% percentile interval of the optimal routing cost solution lies between $238,940.7 and $247,171.35. If the Northern Distribution is disbanded the 90% percentile interval is between $275,570.64 and $285,942.93. If the Northern Distribution centre were to be disbanded, our simulation suggests that the Warehouse Group would save at least $361,000 per month in comparison to using both Distribution centres during this period.

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2. Introduction

The Warehouse Group operates a fleet of trucks that deliver pallets from their two distribution centres to Warehouse and Noel Leeming stores around Auckland. We hope to decide suitable routes for the fleet of trucks that minimizes transportation costs, considering the constraints defined.

From the project, we hope to generate a large amount of feasible trucking routes that will be used in the mixed-integer program to decide the least-cost routing schedule. We also hope to conduct a simulation that takes into account the variations in demand and approximate traffic sensibly. This will allow us to answer whether closing the Northern Distribution centre would be beneficial to the Warehouse Group, as opposed to using both distribution centres.

3. Methods

From the data given, we estimated the number of pallets required weekly and on Saturday's in order to meet demand, and created a map of locations that will be visited in the by the trucks, which have been split by sub-region. Using our mean pallet demands, we generated a set of feasible trucking routes that satisfied our model requirements. This was solved using a mixed integer program that found the least-cost routing schedule for the truck fleet, which we visualized to show our proposed trucking routes. Considering the affect of varying pallet demands and traffic, we ran a simulation to assess the quality of our results.

3.1 Data Analysis

The Warehouse Group have provided us with the following data:

- The number of pallets delivered to each store over a 4-week period
- The GPS coordinates of each store
- The road distance (in metres) and travel durations (in seconds) between stores and distribution points

We plotted the daily mean demand of pallets over the 4-week time period (rounded up to the nearest integer), considering separate cases for weekdays and Saturday's. This was done so that we could see the differences in trend of daily pallet requirements depending on the day.

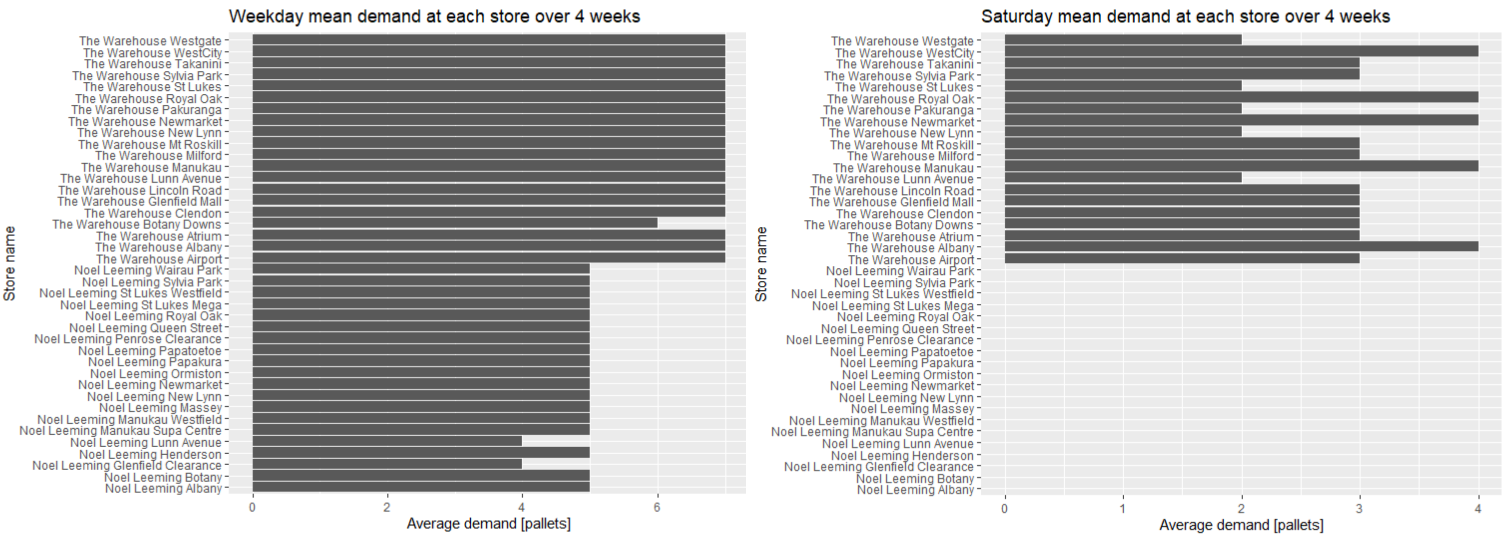


Figure 1: Each store's daily mean demand of pallets required to meet total demand over a 4-week period on Weekdays (left). Each store's daily mean demand of pallets required to meet total demand over a 4-week period on Saturdays (right).

After reviewing the data given to us, we found that on Saturdays pallets were only delivered to Warehouse stores, and not Noel Leeming stores, and on all Sundays no pallets were delivered to either store, which allowed us to remove Sunday deliveries from our analysis of the problem.

On weekdays, the range of the mean pallets required was between 4 and 7 pallets, and on Saturday's, the range of the mean pallets required was between 2 and 4 pallets. This trend showing that the average demand over the 4-week period decreases on Saturday's compared to Weekdays, in order to meet the total demand. Also, by rounding up to the nearest whole pallet we may be over-stating the demand required thus increasing the costs slightly by delivering more pallets than required.

We also plotted the general locations of the stores being visited on a map to get an idea of where our trucks will be visiting.

The two distribution centres are located slightly North and South of the large cluster of stores seen at the centre of the map. It is also seen that there is overlapping of some store locations, which helped us decide on where our various clusters of stores being visited will be grouped. So that we can provide the most optimal routes.

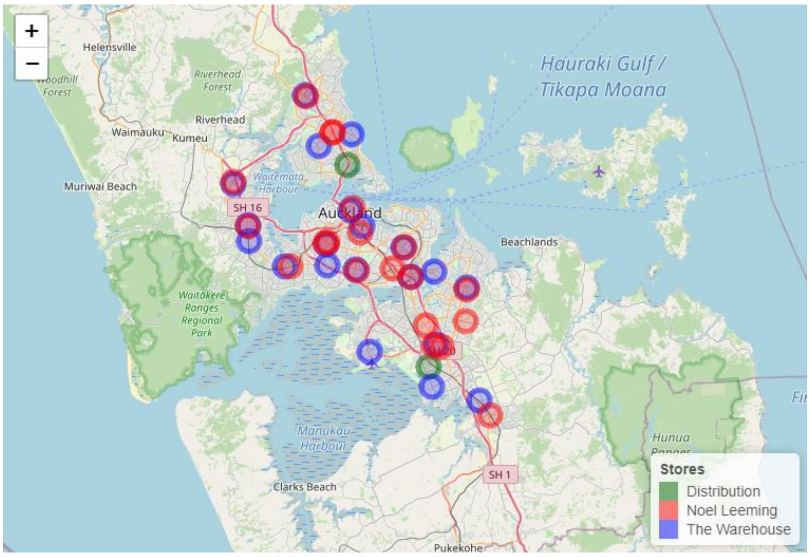


Figure 2: Map of classified stores & distributions

3.2 Route Generation

3.2.1 Group division by location

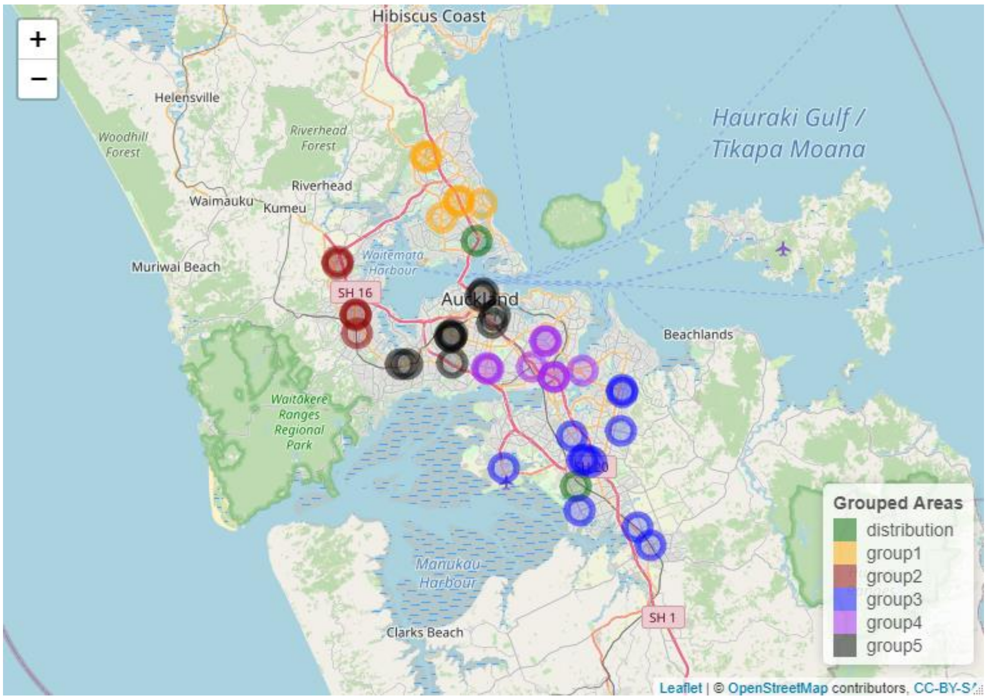


Figure 3: Map showing classified groups of stores & distributions.

From figure 2, we recognized 5 different clusters of stores grouped up, this was done to ensure that the routes would be appropriately generated depending on the specific group (figure 3) i.e. no optimal truck route delivers to stores across the different groups. The algorithm that we have developed loops through each of the different groups noted and creates as many possible routes within the cluster for the trucks to deliver the demand to the stores. By doing this we may get cases where trucks may have completed their scheduled routes but still had space to deliver more pallets to other stores near-by that weren't in the current cluster, and instead the trucks go back to the distribution point. This may cause our costs to increase.

When we consider that the Northern Distribution supply is open, groups 1,2 and 5 will begin and end here and groups 3 and 4 will be coupled with the Southern Distribution supply. Otherwise if the Northern Distribution centre is closed, all routes begin and end at the Southern Distribution.

3.2.2 Route Generation Algorithm

For each group in figure 3, we generated an algorithm that created 1000 randomly generated feasible routes (giving us a total of 5000 total feasible routes generated). For every route generated, the algorithm works as follows, we start with an initial route containing no stores, a store will then be chosen at random from the current group. This store is added to the route if the time taken to go through the updated route (including the current store) that starts and ends at the current supply is less than 6 hours and the total demand of this updated route is less than 20 pallets. (The time taken being calculated by considering both the travel time and unloading times). If the store was added, then another store is chosen at random and the procedure is repeated. Otherwise the algorithm is ended, and the route is saved.
Note: given that on Saturdays, all Noel Leeming stores have a demand of 0, these stores have not been considered when selecting a store at random from the current group.

3.2.3 Problems Encountered

While working toward the solution, we noticed that setting a constraint that every route must be completed within 4 hours resulted in all pallets not being able to be delivered to the stores if the North Distribution supply is disbanded. Therefore, the truck drivers would be required to exceed their 4-hour shifts should the North Distribution be disbanded, which is something we need to take into consideration when choosing the most optimal truck routing scheme. We made the assumption that it would not be a big issue to adjust the truck drivers' working times to allow for 6-hour trips. This allows for feasible solutions when closing the North Distribution, these solutions being accordingly penalised in the objective function of the linear program.

3.3 Optimisation Model Formulation

We formulated this problem as a vehicle routing problem (VRP), considering the enumeration of many feasible routes. The full formulation can be found in Appendix A.

Objective Function:

We are looking to minimise the total cost of the routing-schedule.

$$MIN \quad \frac{175}{3600}\sum_{i=1}^{N} c_i\, x_i + \frac{175}{3600}\sum_{j=1}^{M}(4\times 3600)\, x_j + \frac{250}{3600}\sum_{j=1}^{M}\left(c_j - 4\times 3600\right)x_j$$

Where c is the routes time taken or *'cost'* in seconds and *N* and *M* are a set of routes from *K* which have $c_i \leq 4 \times 3600$, and $c_j > 4 \times 3600$ respectively, and x_i, x_j are binary switches for routes.

Constraints:

- The Warehouse Group operates a fleet of 25 total trucks.
- Each truck carries up to 20 pallets of goods.
- Each store receives one delivery daily.
- Each truck costs $175/hour to operate and can operate two four-hour shifts daily.
- If extra time is required to deliver pallets trucks cost $250/hour to continue operating.
- A store is only visited if the average demand is greater than 0 pallets.

While solving the linear program, we noticed that the GUB constraint for the number of trucks is non-binding. This meaning that in the formulation it was deemed unnecessary to include additional variables, labelled 'wet-leasing', for the purchase of extra trucks from Mainfreight.

3.4 Visualizations of Routes

For the route visualisations in Appendix B & C, we have not taken into account any traffic nor the variation in demand, but merely the time it would take to get between locations. This is to be considered in the simulation section. In reality, this will cause the costs seen to be smaller than they actually are.

There is some clear instances of 'petalling' occurring around both North and South Distribution centres in Appendix B where the Northern Distribution centre remains open. This indicates that our results are relatively well done and suggests that they are near optimal if not optimal when there is no variations in demand and traffic.

3.5 Simulation

In order to evaluate the quality of the schedules that we have created, we have undergone 1000 Simulations to appropriately take into account the variations in demand from day to day, and sensibly approximate the effect of traffic.

With the intention of sensibly approximating the impact of traffic, we applied two randomly generated multipliers between the calculated range (given in Appendix Ei) to our 'costs' variable (time taken variable). For weekdays this meant a larger 'overall variation' multiplier range due to the constant traffic throughout the day all 5 days of the week. This was calculated by averaging out the total traffic congestion (Appendix E) between 8am and 6pm throughout all the days of the week. For Saturday, the 'overall variation' multiplier range was smaller due to the lack of traffic compared to working days, and was calculated much the same as the weekdays case, however just including the average Saturday traffic congestion between 8am and 6pm. For both the Weekdays and Saturday costs, we also applied an 'individual variation' which accounted for the variation in space with traffic, considering events such as traffic lights, weather, and/or car accidents.

To appropriately consider the variations in demand from day to day, we bootstrapped the demand data given to estimate the randomness that can be seen in industry. This resulted in some routes that may have exceeded 20 pallets, for every route that exceed 20 pallets we removed the store with the smallest demand that allowed a feasible route containing less than 20 pallets to be used. These stores were added to a new route which would be visited by one spare truck each, meaning that we generated separate routes for each location that required pallets. This can be seen in Appendix K.

As we can see from Appendix F, the results suggest the number of trucks required on weekdays (considering the effect of traffic and varying demand) varies as a normal distribution between 16 and 24 trucks, and on Saturday's the number of trucks required is constant at 5 trucks. This is a good sign, meaning we are confident that the number of trucks required will stay below the maximum available trucks in the fleet of 25.

4 Results

4.1 Model Summary

We found that 21 total routes were generated with and without the removal of the Northern Distribution centres. Of these, 16 routes were scheduled for Weekdays and 5 for Saturday's for both respective cases.

However, the total costs of transporting pallets varied between our two options. If we used both the Northern and Southern Distribution centres, then we would incur a total daily cost of $9,317.72 on weekdays and $2,958.21 on Saturdays (Appendix D). If we just used the Southern Distribution centre, then we would incur a total daily cost of $10,332.62 on weekdays and $3,311.56 on Saturdays. This equates to a total routing cost of $198,187.24, and $219,898.64 (Appendix J) respectively, meaning $21,711.4 more in travel costs are suffered every month if we choose to close the North Distribution centre.

In saying this, by closing the Northern Distribution centre, overall The Warehouse Group would benefit by saving $378,290 a month during this period (evaluating both options against each other) due to not having to maintain this centre, given that transportation costs aren't the only cost being considered. This comes at the price that truck drivers work up to 6 hours per route.

4.2 Simulation Summary

From Appendices E & F, we can see that during weekdays when we run 1000 Simulations on the weekday cost for both distribution centres being open, the 90% percentile interval of where our solution lies is between $10,768.54 and $12,395.95. This being much smaller than when the Northern Distribution is disbanded, which generated a 90% percentile interval of $12,441.65 to $14,330.68. Our modelled results were generally lower than the ranges found here due to taking traffic multipliers into consideration in the simulation which has increased the relative costs.

The Saturday 90% percentile intervals are much closer being between $2,704.26 and $3,266.5 when both Distribution centres are open compared to $3,111.32 to $3,720.12 when the North Distribution centre closes. From Appendix D, the modelled route's Saturday Costs are within this range which is a good sign to see. This may be due to Saturday's having lower traffic multipliers which meant that the relative costs did not fluctuate as much.

From Appendix J, the 90% percentile interval if both distribution centres are used results in an optimal routing cost solution that lies between $238,940.7 and $247,171.35. Given that the Northern Distribution is disbanded the 90% percentile interval is between $275,570.64 and $285,942.93. The 90% percentile for the difference in costs between our two options is between $36,384.75 and $38,998.95. Our costs in the model are understated due to considering the effects of the traffic multipliers during simulation. In saying this the results are similar, should the Northern Distribution centre be disbanded the Warehouse Group would save at least $361,000 per month, with maximum savings being up to $363,615 per month.

5 Discussion

5.1 Recommendation

According to the results, what we would recommend to the Warehouse Group is to close the Northern Distribution centre. Although the transport costs increase if we do this, the Warehouse

Group saves an additional $400,000 in other costs such as maintaining this distribution centre. If this is done, we would be fairly confident that the Warehouse Group will save at least $361,000 by choosing this option rather than keeping both open if we were being pessimistic, the upside is saving $363,615 if we were being optimistic.

We would also recommend that 16-23 trucks are active during weekdays, which vary daily depending on the requirements (demand), and 5 trucks be consistently active during Saturdays.

5.2 Drawbacks of Model

A limitation of our model may be when considering traffic, we calculated an average multiplier between 8am and 6pm, which helped us develop a range. We then randomly generated between the multiplier from this range from a uniform distribution. However, in reality different times of the day have different traffic congestion rates, seen in Appendix E. It may have been more appropriate to generate separate multipliers between different ranges for the different time periods during the day instead of generalising it as one overall multiplier for the day as a whole. For example, congestion rates at 8am and 5pm more intense than say at 12pm, also seen in Appendix E.

Another model restriction that we noticed is that we have based this report primarily on one months' worth of data that has been given. This is a limitation because other months may have different requirements and will require resolving in order to get the most optimal solution if demands change for example. However, in saying this, we are fairly confident that the Northern Distribution remaining closed would still be the best decision given the changes aren't too drastic, but the routing-schedule may be changed as a result of resolving.

6 Conclusion

In conclusion, we had a task of helping the Warehouse Group determine a suitable truck logistics plan that minimized costs which included making many assumptions noted in the report. We did this by completing the following set of tasks:

- Estimated the number of pallets required daily at each store through data analysis.
- Created a set of feasible trucking routes that satisfied requirements given for both distribution centres being open and the North distribution centre closing
- Formulated and solved a mixed-integer program to find the least-cost routing schedule for this specific truck fleet
- Created visualisations of our proposed trucking routes on a map
- Created a simulation to evaluate the quality (cost) of our proposed trucking schedules by taking into account variations in demand and the effects of traffic

6.1 What's Next?

Although our model appropriately answered the questions posed by this report, there are always improvements that can be made. This may include the following:

- Generating different traffic multipliers based on the different time period's that the truck is visiting stores. Which would make the simulation results more accurate.
- Generating different routes for different days of the week, instead of generating a set of routes for Weekdays and Saturday, respectively. This could further optimise the solution as through closer inspection there may have been other trends in the data.
- The re-supply of trucks during trips may also have further optimised the solution.
- Increasing the number of pallets that can fit on the truck.

7 Appendices

Appendix A: Model Formulation

Decision Variables:

For a set of K routes, we have

$$x_k = 1 \; if \; route \; k \; used \; in \; the \; routing \; plan$$

$$0 \; otherwise$$

Where $1 \leq k \leq |K|$ and x_k is a binary switch for routes.

Objective Function:

$$MIN \quad \frac{175}{3600}\sum_{i=1}^{N} c_i \, x_i + \frac{175}{3600}\sum_{j=1}^{M}(4 \times 3600)\, x_j + \frac{250}{3600}\sum_{j=1}^{M}\left(c_j - 4 \times 3600\right)x_j$$

Where c is the routes time taken or *'cost'* in seconds and *N* and *M* are a set of routes from *K* which have $c_i \leq 4 \times 3600$, and $c_j > 4 \times 3600$ respectively.

Constraints:

In the network of stores, for each store if the demand of a store exceeds 0, and the store is visited by the route in the set the following constraint is added:

$$\sum_{x_k \in A}^{A} x_k = 1$$

Where $A = \{x_a, x_b, \ldots\}$ and x_a, x_b are the routes.

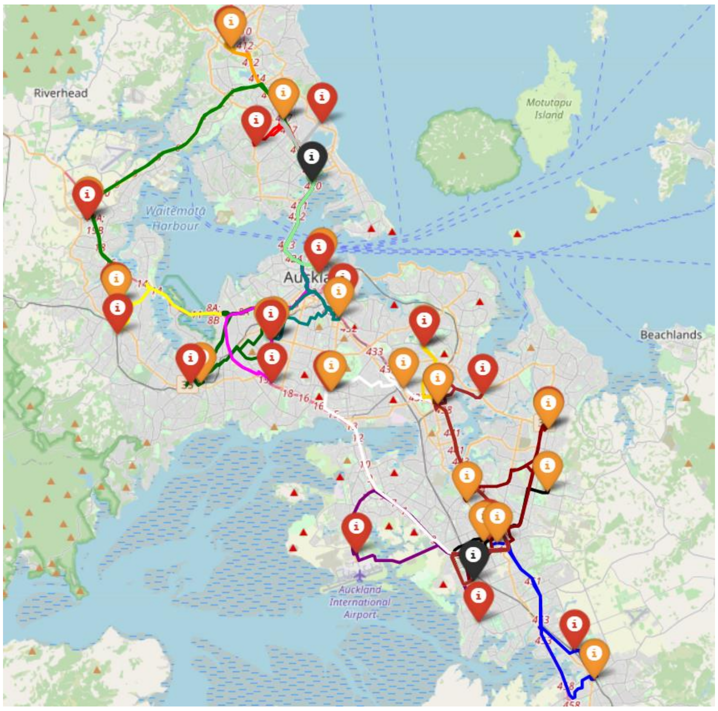
Number of trucks available to be assigned to routes is less than 25 :

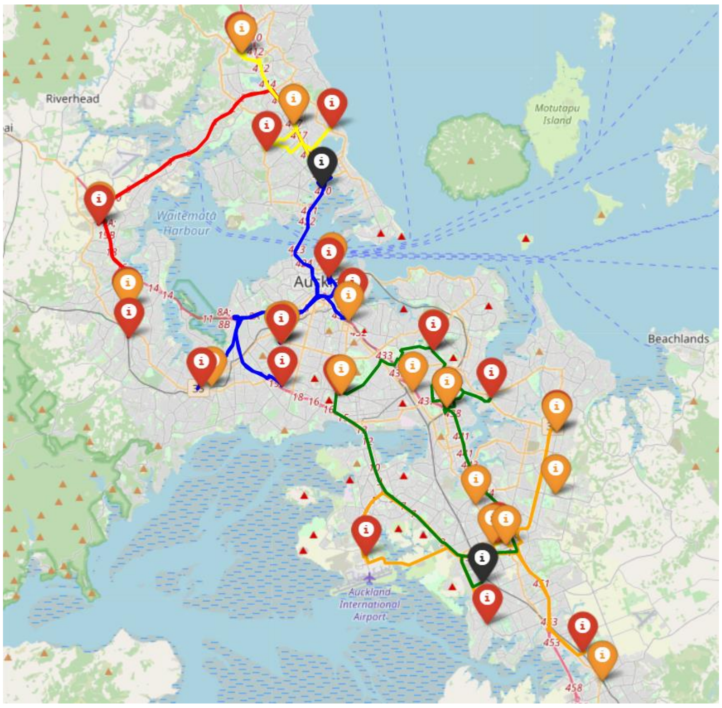
$$\sum_{k=1}^{K} x_k \leq 25$$

Non-negativity, binary constraints:

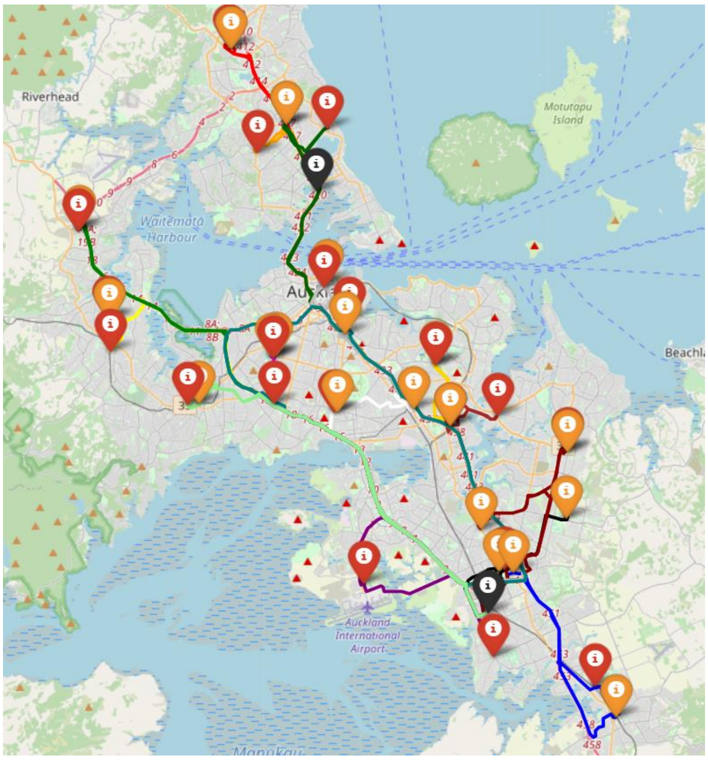
$$x_k \geq 0, binary$$

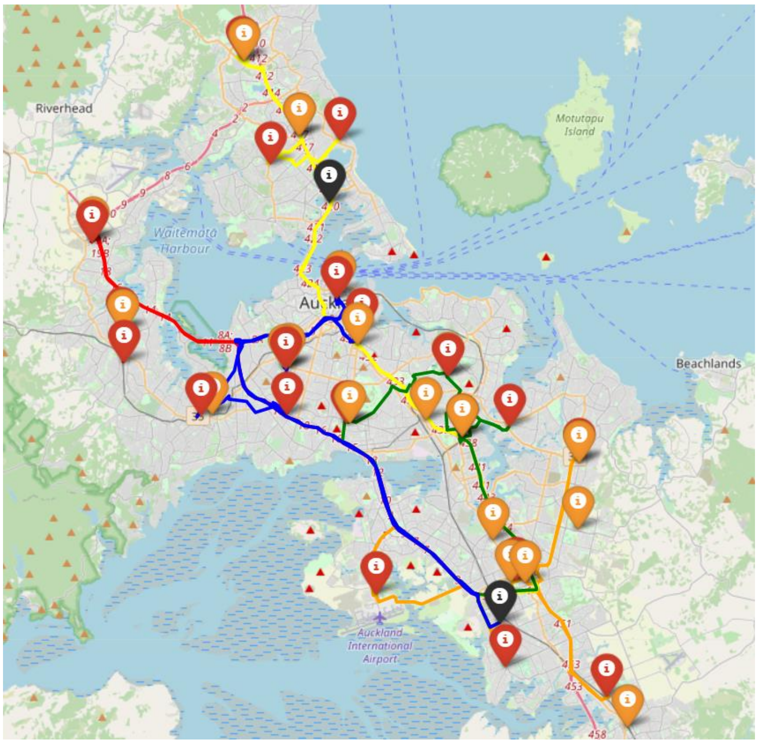
Appendix B: Route Visualizations for Weekdays (left) and Saturdays (right) if the Northern Distribution Centre remains open.





Appendix C: Route Visualizations for Weekdays (left) and Saturdays (right) if the Northern Distribution Centre is disbanded.

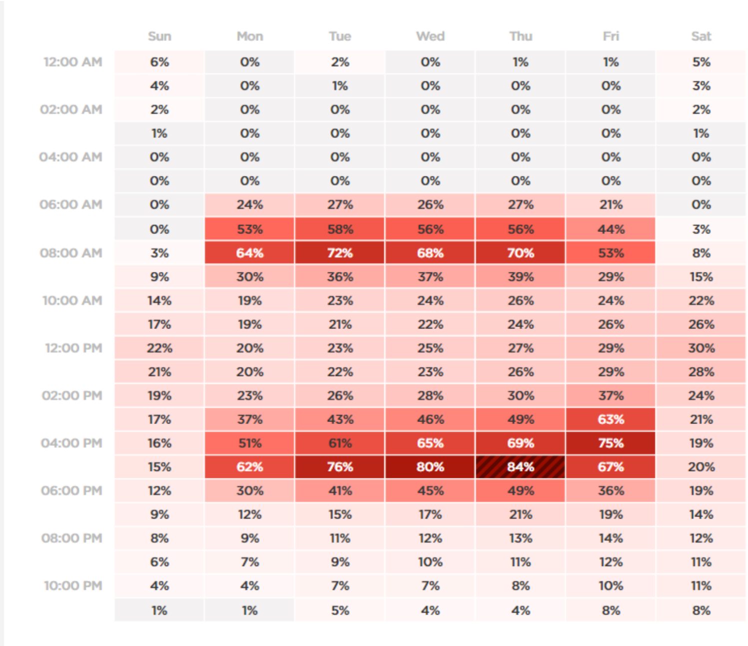




Appendix D: Table of the Model Costs

Using both Northern and Southern Distribution Points	
Single Weekday Cost	$9,317.72
Single Saturday Cost	$2,958.21
Total Weekly Cost	$49,546.81
Total Monthly Cost	$198,187.24
Removal of Northern Distribution Point	
Single Weekday Cost	$10,332.62
Single Saturday Cost	$3,311.56
Total Weekly Cost	$54,974.66
Total Monthly Cost	$219,898.64

Appendix E: 2019 Average Weekly Congestion Plot (TomTom)

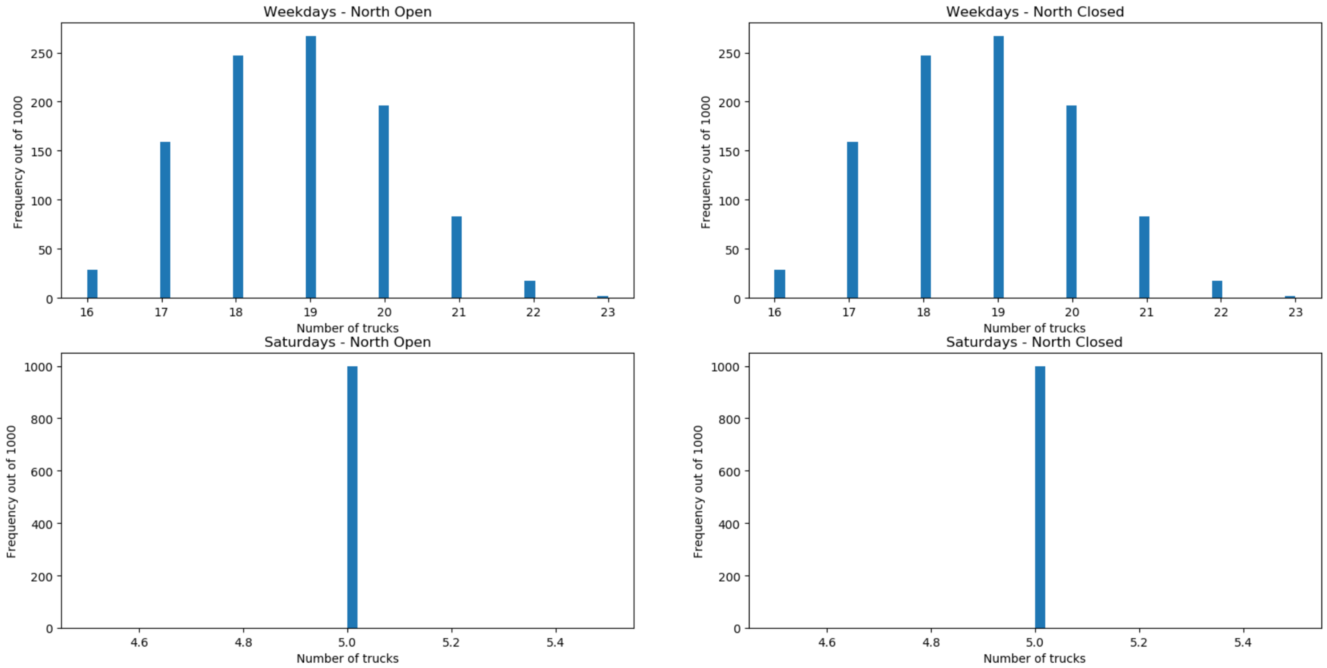


	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12:00 AM	6%	0%	2%	0%	1%	1%	5%
	4%	0%	1%	0%	0%	0%	3%
02:00 AM	2%	0%	0%	0%	0%	0%	2%
	1%	0%	0%	0%	0%	0%	1%
04:00 AM	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%
06:00 AM	0%	24%	27%	26%	27%	21%	0%
	0%	53%	58%	56%	56%	44%	3%
08:00 AM	3%	64%	72%	68%	70%	53%	8%
	9%	30%	36%	37%	39%	29%	15%
10:00 AM	14%	19%	23%	24%	26%	24%	22%
	17%	19%	21%	22%	24%	26%	26%
12:00 PM	22%	20%	23%	25%	27%	29%	30%
	21%	20%	22%	23%	26%	29%	28%
02:00 PM	19%	23%	26%	28%	30%	37%	24%
	17%	37%	43%	46%	49%	63%	21%
04:00 PM	16%	51%	61%	65%	69%	75%	19%
	15%	62%	76%	80%	84%	67%	20%
06:00 PM	12%	30%	41%	45%	49%	36%	19%
	9%	12%	15%	17%	21%	19%	14%
08:00 PM	8%	9%	11%	12%	13%	14%	12%
	6%	7%	9%	10%	11%	12%	11%
10:00 PM	4%	4%	7%	7%	8%	10%	11%
	1%	1%	5%	4%	4%	8%	8%

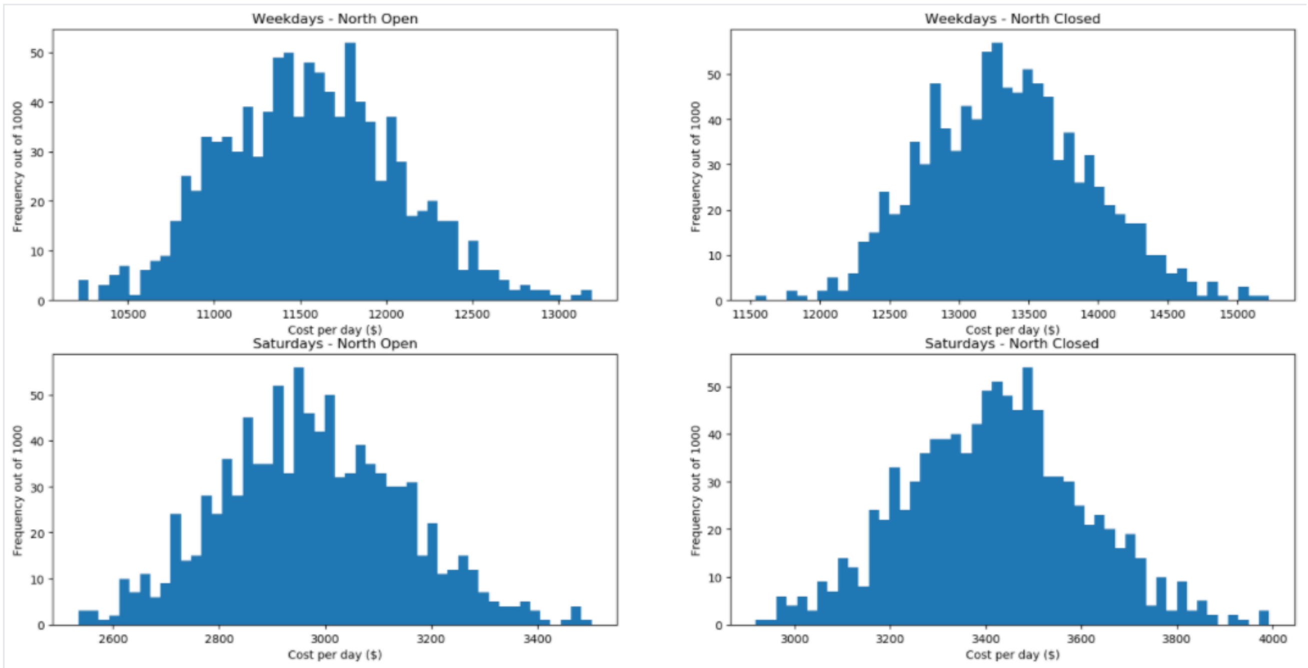
Appendix Ei : Table of Multipliers used to consider Traffic

Variation Type	Traffic Multiplier (Uniformly distributed interval)
Overall Variation (Weekly)	[1.31, 1.51]
Overall Variation (Saturday)	[1.11, 1.31]
Individual Variation (both)	[0.85, 1.15]

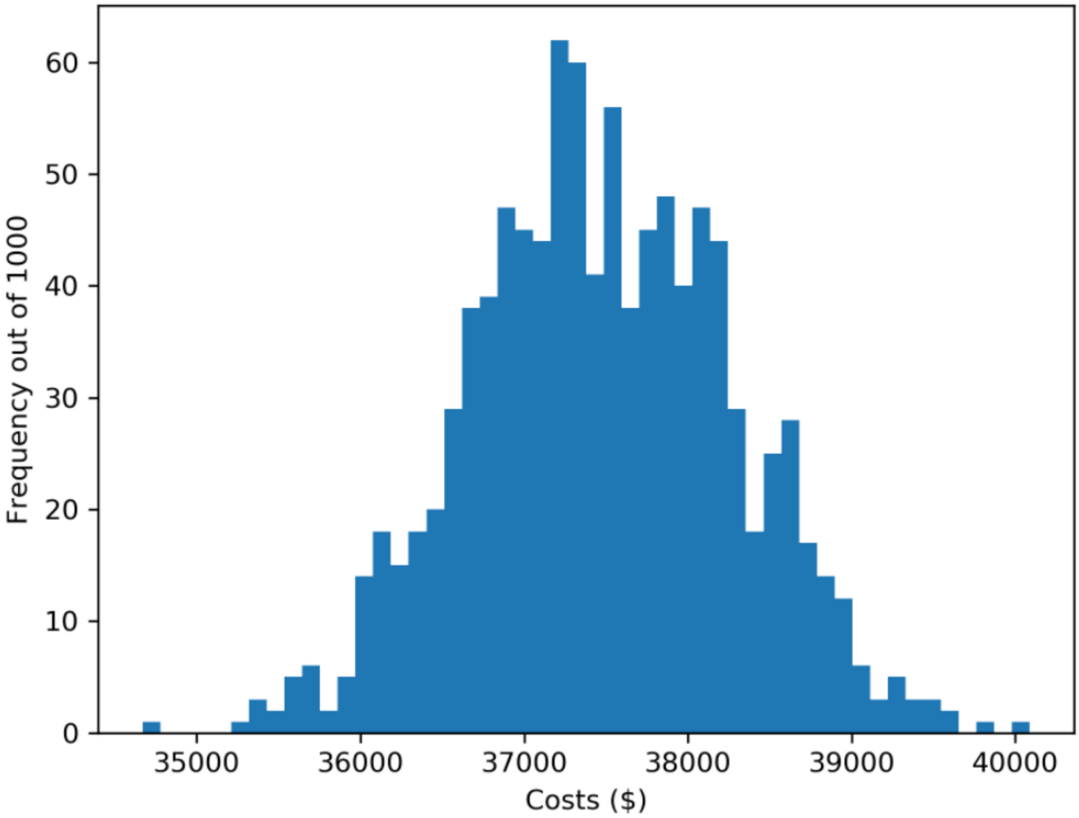
Appendix F: Histogram showing Truck Variation for 1000 Simulations



Appendix G: Histogram showing Objective Function Costs for 1000 Simulations



Appendix H: Histogram showing Extra Costs per Month for 1000 Simulations



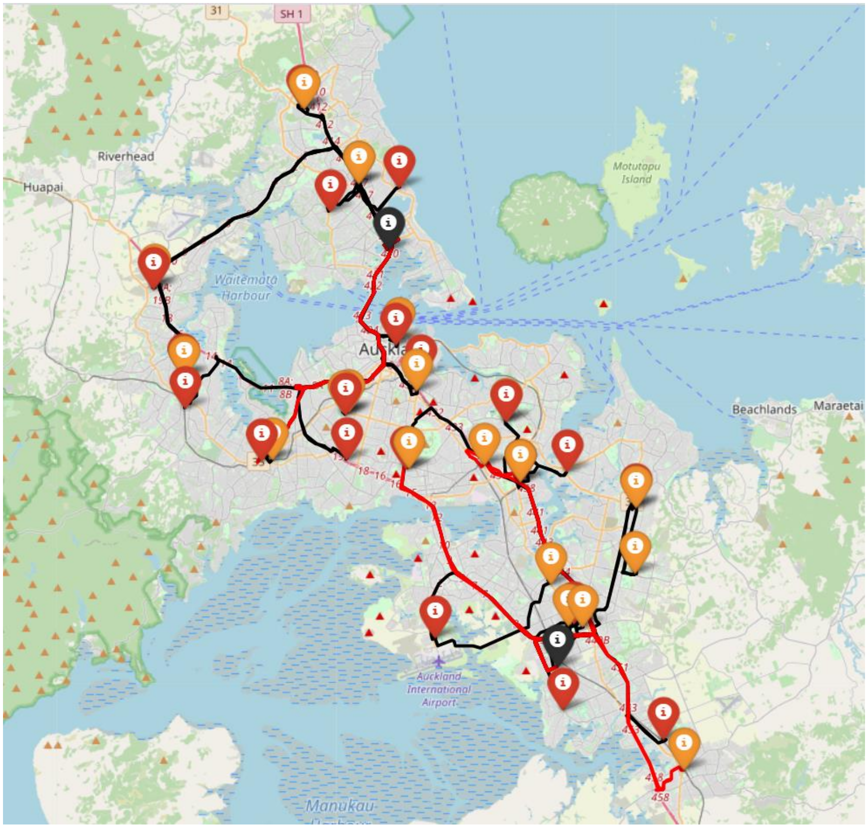
Appendix I: 90% Percentile Intervals of Costs per day

Scenario	5% Lower Bound	5% Upper Bound
Weekdays, both distributions open	$10,768.54	$12,395.95
Saturdays, both distributions open	$2,704.26	$3,266.5
Weekdays, North distribution closed	$12,441.65	$14,330.68
Saturdays, North distribution closed	$3,111.32	$3,720.12

Appendix J: 90% Percentile Intervals of Costs per month

Scenario	5% Lower Bound	5% Upper Bound
North Distribution Open	$238,940.7	$247,171.35
North Distribution Closed	$275,570.64	$285,942.93
Extra Costs per Month	$36,384.75	$38,998.95

Appendix K: Route Visualizations for bonus trucks (seen in red).



8 References

1. TomTom. (2020). Auckland Traffic. TomTom. https://www.tomtom.com/en_gb/traffic-index/auckland-traffic/