TRUCK SCHEDULING FOR FOODSTUFFS

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1 Executive Summary

Foodstuffs are looking to find the best trucking routes to deliver pallets of goods such that transportation costs are minimised. Methods such as analysing data provided by Foodstuffs to establish pallet demands, applying several assumptions and simplifications to generate feasible routes and formulating a mixed-integer program were used to find the optimal routing schedule for weekdays and Saturdays, which were then visualised through maps. This resulted in costs of $10123.47 and $5387.99 per day to deliver all required pallets for weekdays and Saturdays respectively.

Simulations were done to show the effects of varying pallet demands and traffic conditions on trucking route costs. For our weekday simulation, the median objective cost was $10936.03, and a 95% confidence interval was constructed with lower and upper bounds of $10689.66 and $11252.96 respectively. The median objective cost for our Saturday simulation was $3031.04, and a 95% confidence interval was constructed with lower and upper bounds of $2918.54 and $3283.63 respectively. To minimise transportation costs, it is recommended to use all Foodstuffs trucks and ‘wet-lease’ four Mainfreight trucks on weekdays, while only use seven Foodstuffs trucks on Saturdays.

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2 Introduction

Foodstuffs operate and supply pallets of goods to various supermarket chains around Auckland through their trucking division, which transports pallets from the central distribution warehouse to each store. We would like to determine the best way to route truck such that transportation costs are minimised while satisfying the given constraints. These constraints will be discussed further in the Methods section.

From this project, we hope to obtain a set of feasible and realistic trucking routes, as well as gain a better understanding of the effects of varying pallet demands at each store and traffic conditions on every truck route through simulation.

3 Methods

To solve our problem, we first analysed the given data to establish pallet demands from individual stores and the travel times between them. We then applied several assumptions to our model and created a set of feasible routes, which were used to generate the optimal trucking routes. Visualisations from these optimal routes were also created, and their quality was evaluated by implementing the variations in demand and the effect of traffic into our model.

3.1 Analysing Given Data

We were provided with the following data from Foodstuffs:

- Number of pallets delivered to each store over a four-week span.
- The GPS coordinates of each store.
- The travel distance and mean travel time between each store.

We plotted bar graphs of the total pallets for all stores and a couple individual stores over the four-week span to see the overall trend between days of the week and pallet requirements.

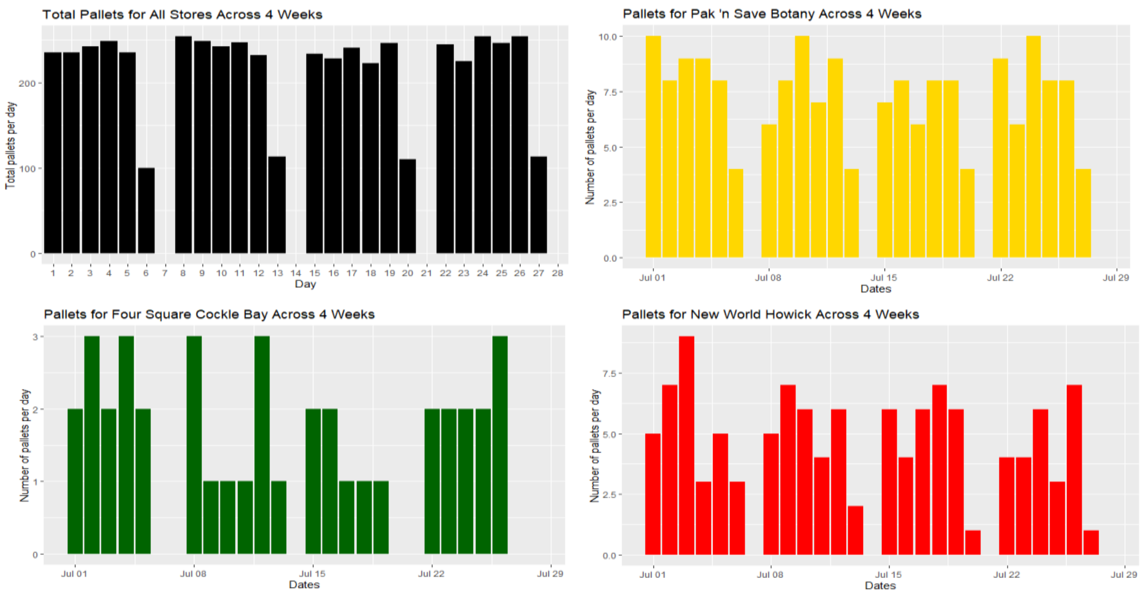


Figure 1. (top left) Total pallets for all stores across the four-week span. (top right) Pallets for Pak 'n Save Botany across four-week span. (bottom left) Pallets for Four Square Cockle Bay across four-week span. (bottom right) Pallets for New World Howick across four-week span.

The total weekday demands are approximately constant and appear to have a mean of 240 pallets per day. On Saturdays, the pallet demand seems to be slightly less than half that of a weekday, at around 110 pallets. On Sundays, there are no pallets delivered to any store. We will assume that this pattern of pallet demand will continue as the weekly data is consistent across the four-week span.

We also compared the number pallet demands per day for each type of Foodstuffs supermarket to get a better grasp on the differing demand between supermarkets. This was plotted as a boxplot in Fig. 2.

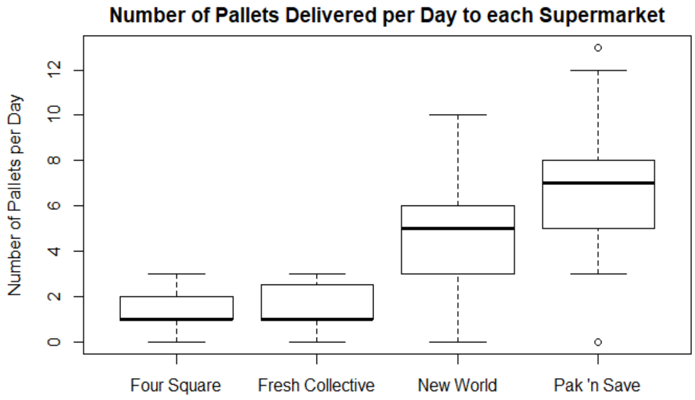


Figure 2. Number of pallets delivered per day for each type of supermarket per day.

We see that Four Square and Fresh Collective supermarkets both have the lowest median number of pallets per day, at 1, as well as a spread of 3. New World stores have a larger median number of pallets per day, at 5, and a larger spread of 10. We also see that Pak ‘n Save supermarkets have the largest median number of pallets per day, at 7, and the largest spread of 13.

Since a trip can carry a maximum of 12 pallets, any deliveries to stores greater than 12 pallets were removed from the data. This was done to simplify our model, although in reality, it is entirely possible for a store to have a pallet demand greater than 12. We also estimated the pallet demands for each store for both weekdays and Saturdays by rounding the median demand to the nearest integer.

3.2 Optimisation Model

3.2.1 Route Generation

We separated the stores into four different regions so that there would not be an overwhelming number of routes generated (Fig. 3). We assumed that trucks only delivered to supermarkets in that region during their route. This will likely lead to several inefficient truck routes where trucks may still have undelivered pallets yet go back to the distribution warehouse instead of delivering them to stores outside of the current region; the cost will increase.

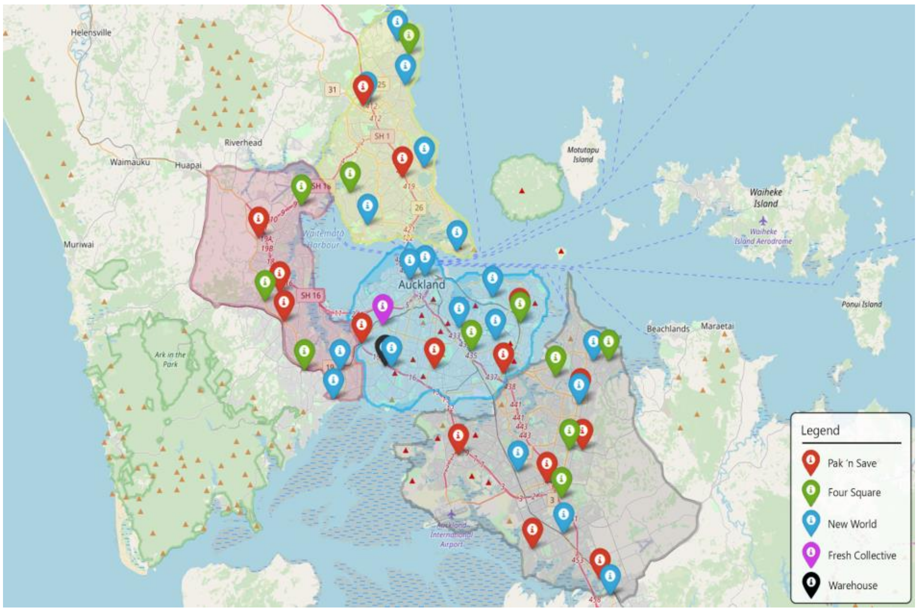


Figure 3. A Map of Foodstuffs supermarkets, split by region (North, West, Central and South-East).

A couple more assumptions were made to additionally simplify our problem:

- All trucks are limited to one route (a simple circuit starting and finishing at the central distribution warehouse) per four-hour shift – equivalent to two routes per truck each day. This removes any truck routes that can return to the central distribution warehouse and resupply pallets for further deliveries, which may lead to several inefficient truck routes and therefore an increase in cost.
- Mainfreight trucks may not operate longer than their designated four-hour shift. This means that there may be more routes taken by Mainfreight trucks than needed. However, the overall cost is unlikely to be significantly affected as Mainfreight trucks are 'wet-leased' at a fixed cost.
- Foodstuffs trucks may operate longer than their designated four-hour shift but are limited to an extra 30 minutes. Thus, routes longer than four and a half hours will not be generated, and so more routes may be created than required. This will likely result in transportation costs greater than actually required.
- The given median travel times will be used, and traffic conditions will be ignored – we will try to account for these conditions in Model Simulation. This assumption will probably cause our costs to be less than what may be seen in reality.

To generate the routes, we found all possible simple circuits in each region beginning and finishing at the warehouse. This was done using a recursive approach that works like a depth-first search: go down a path until a condition or assumption is not satisfied, append the arc returning to the warehouse, pop the last node and move to the next node that has not been visited. The routes were verified to ensure they were within the constraints given by the problem brief and by our assumptions. For our routes on Saturday, we further constrained them to have a maximum length of 5 nodes to make sure runtime was not unreasonable.

3.2.2 Formulating Model

The constraints which were provided for modelling include:

- Foodstuffs has 10 trucks.
- Each truck can carry a maximum of 12 pallets.
- Trucks cost $150 per hour and can operate two four-hour shifts per day.
- Trips should take no longer than 4 hours, on average. However, if 4 hours is exceeded there will be a cost $200 per extra hour.
- Each store only receives one delivery per day.
- Mainfreight trucks can be 'wet leased' for a fixed cost of $1200 per four-hour shift.

Considering the assumptions from our route generation, we formulated our optimisation model using a linear approach, with the full formulation provided in Appendix A. Below is the objective function:

minimise total cost $\sum_{i=0}^{n} x_{fi} c_i + \sum_{i=0}^{n} x_{mi}\, c_m$

where c_i is the cost of the route i, c_m is the cost of a Mainfreight four-hour shift i.e. c_m = \$1200, n is the number of routes, x_{fi} is a binary switch for normal trucks (Foodstuffs) and x_{mi} is a binary switch for 'wet leased' trucks (Mainfreight).

3.3 Visualisation of Routes

From Appendix B and C, we notice that most Mainfreight truck routes are typically longer than Foodstuffs truck routes on weekdays. This is because Foodstuffs trucks seem to not extend out to supermarkets in far northern, eastern or southern areas in our optimal solution, likely due to Foodstuffs trucks being assigned routes that had been generated first.

From Appendix D, we notice that no Mainfreight trucks have been used on Saturdays, which is probably due to the pallet demand on Saturdays being around half that of weekdays. This means that the ten Foodstuffs trucks will be sufficient to deliver all the required demand on Saturdays.

To better visualise the distance of each route, we also constructed abstract maps for both weekday and Saturday trucking routes, seen in Appendix E. These represent the displacements between two stores as a straight line.

3.4 Model Simulation

We have conducted 500 simulations for both weekday routes and Saturday routes to estimate the actual cost of satisfying the pallet demand at each store. The simulation involved random variations in demand by each stores and random fluctuations in traffic conditions.

To model the traffic conditions during weekdays, we applied a multiplier for each specific hour in both shifts and assumed it to be constant throughout the hour. This meant that we used four multipliers for each shift, with the value of every multiplier being randomly generated between two values, which we decided from our own experience. For weekends, we assumed the traffic conditions to be constant throughout both shifts. These multipliers are shown in Appendix F.

In reality, traffic conditions are affected by various factors such as weather, roadworks, traffic lights and accidents, and are never constant, so cannot be accurately modelled by constant multipliers. Furthermore, different areas have different traffic flows (for example, traffic conditions on a motorway will be different to that in a rural area,) so each truck route will have different traffic conditions and flows. Since our model does not account for these factors and assumes constant multipliers for each hour, it is expected that our results will be less spread and have less variability than what would be seen in reality.

To model the variation in pallet demand from store to store, we analysed the data given by Foodstuffs and looked at how many pallets were delivered to each store. We recorded the frequencies of the different pallet demands for both weekdays and Saturdays, which we then used to form the probabilities of specific pallet demands for each store, as seen in Appendix G. Finally, the actual demands for every supermarket were randomly generated based on the probabilities formed.

The main assumption we made in simulating the varying demands was that the given data was a good and true representation of pallets required at each store. However, since the data given only spans four weeks, it is unlikely to be a true representation of pallets required at each store. Thus, it is expected that our results will have less spread than what would be seen in reality.

4 Results

4.1 Summary of Routes and Initial Costs

The weekday and Saturday truck routes are shown in Appendix H. These took around five and ten minutes to find respectively.

We see that during weekdays, all ten Foodstuffs trucks have been deployed and twenty routes have been taken by these trucks, as well as four routes being taken by Mainfreight ones. This resulted in a total cost of $10123.47 per day to satisfy pallet demand.

On the other hand, we see that on Saturdays, Mainfreight trucks were not used as less than twenty routes were required to meet the pallet demand for all stores. Thirteen routes were thus taken by Foodstuffs trucks, resulting in a total cost of $5387.99 per day to deliver all pallets.

4.2 Summary of Simulation Costs

The results of our simulations for both weekdays and Saturdays can be seen in Appendix I and Appendix J respectively, with each simulation taking around five seconds to run.

For our weekday simulation, the median objective cost was $10936.03 which was slightly larger than the initial median cost on weekdays. This is likely due to the traffic multipliers causing a longer travel time and thus a higher cost. We also constructed a 95% confidence interval with lower and upper bounds of $10689.66 and $11252.96 respectively. There seem to be a few values having much higher cost than expected, which may be due to using too many Mainfreight trucks to supply the required number of pallets to stores. We expect the high costs to occur roughly 2% of the time.

For our Saturday simulation, the median objective cost was $3031.04, which is a significant amount lower than the initial median cost on Saturdays. This is likely due to rounding the median pallet demand upwards in our initial construction of routes and demands, which meant that nearly all pallet requirements were at least one. In contrast, the randomly generated demands in the simulation could have taken a value of zero, and so stores with a demand of zero would not be visited. We also constructed a 95% confidence interval with lower and upper bounds of $2918.54 and $3283.63 respectively. The upper bound for the confidence interval for Saturday is roughly at the beginning of the higher than expected values. Therefore, we expect the optimal solution to be wrong around 3% of the time.

5 Discussion

5.1 Recommendations

From our results, we see that on weekdays more than twenty routes have been used – all ten Foodstuffs trucks have been deployed, as well as a couple Mainfreight ones being ‘wet-leased.’ To minimise transportation costs, it is thus recommended that on top of all Foodstuffs trucks being used on weekdays, further Mainfreight trucks should be used too; four trucks should be ‘wet-leased.’

We also notice that on Saturdays, there is a fair amount of decrease in routes used compared to weekdays. This is most likely due to Saturdays having significantly less pallet demand than on weekdays, as seen when we analysed the given data. To minimise transportation costs, it is thus recommended that only Foodstuffs trucks, specifically seven of them, be deployed on Saturdays to deliver pallets.

5.2 Model Limitations

As with all models, there will be a number of limitations due to assumptions and simplifications made. One major assumption we made in our model was that stores were conditionally independent of each other. This means that the number of pallets demanded at one store does not affect the pallet demand at another store. However, some stores may be under the same management and could receive the same number of pallets on a given day.

Our model was also limited by the assumption that the given data was a true representation of pallets required at each store, which means that over time, the pallet demands at stores will remain at its current trend. However, with the increasing population and urbanisation, the required number of pallets for each store will be expected to grow as well. This increase in pallet demand has not been accounted for in our model, so it is not recommended to use this model for an extended time period (more than a couple years).

Furthermore, several situations may occur that could cause changes to routes. Regarding traffic conditions, the flow is often changed by events such as car crashes, malfunctioning lights and/or road works. Regarding pallet demand, stores may want to stock up on pallets in during different parts of the year. For example, supermarkets may require more pallets leading up to a public holiday. Again, these events have not been considered in our model.

6 Conclusion

In conclusion, we have determined the best way to route each truck such that transportation costs are minimised while satisfying the given constraints through several assumptions and simplifications. The following have been achieved through this project:

- Feasible truck routes for weekdays and Saturdays.
- Optimal truck routes to take for weekdays and Saturdays.
- Maps containing visualised truck routes.
- Simulation of variations in demand and effect of traffic conditions on cost.

7 Further Implementation

The next improvements that could be implemented into our model are as listed below:

- Allow for trucks to go back to the warehouse to resupply pallets.
- Allow for Mainfreight truck routes to take longer than four hours.
- Allow for Foodstuffs truck routes to take longer than four and a half hours.
- Allow for pallet demands greater than 12.
- Look at specific weekdays instead of just weekdays and Saturdays.
- Apply a traffic multiplier for different areas across Auckland.

8 Appendices

8.1 Appendix A. Optimisation Model Formulation.

Decision Variables:

$$x_{fi} = \begin{cases} 1 & if\ the\ route\ is\ used \\ 0 & if\ the\ route\ isn't\ used \end{cases} \qquad x_{mi} = \begin{cases} 1 & if\ the\ route\ is\ used \\ 0 & if\ the\ route\ isn't\ used \end{cases}$$

where i is the route and x_{fi} is a binary switch for normal trucks (Foodstuffs) and x_{mi} is a binary switch for ‘wet leased’ trucks (Mainfreight).

Objective Function:

minimise total cost $\sum_{i=0}^{n} x_{fi} c_i + \sum_{i=0}^{n} x_{mi}\, c_m$

where c_i is the cost of the route i, c_m is the cost of a Mainfreight four-hour shift i.e. c_m = $1200 and n is the number of routes.

Constraints:

Less than 20 trips taken by Foodstuffs trucks:

$$\sum_{i=0}^{n} x_{fi} \leq 20$$

Each store is visited only once per day:

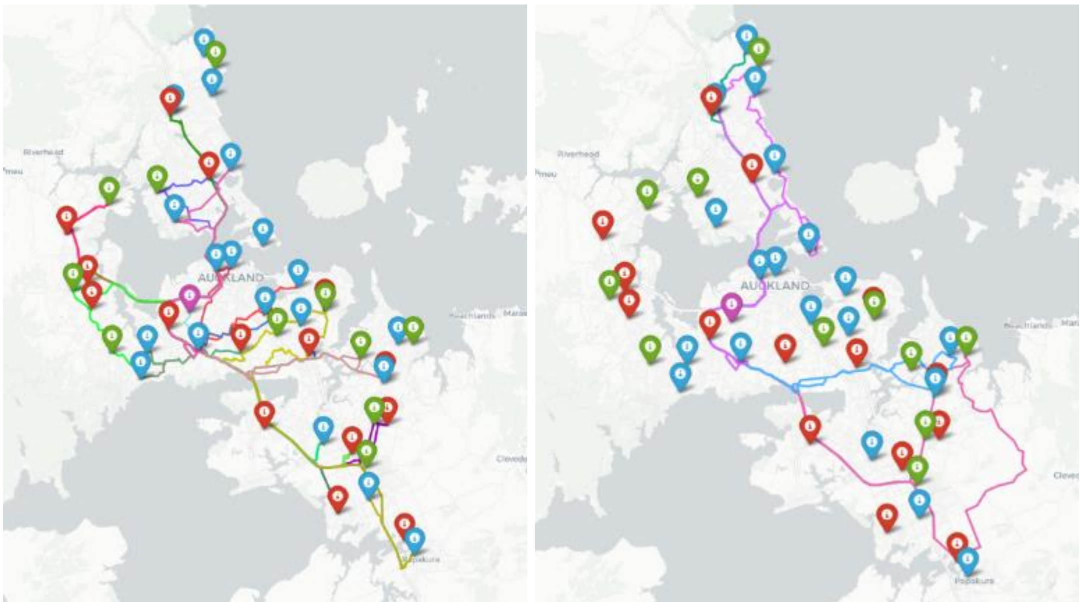
$$\sum_{i=0}^{n} (x_{fi} r_{ji} + x_{mi} r_{ji}) = 1$$

where r is a 2-D binary array of stores and routes. r_{ji} = 1 when route i passes through node j and 0 otherwise.

Non-negativity:

$$x_{fi}, x_{mi} c_i, c_m, r_{ji} \geq 0$$

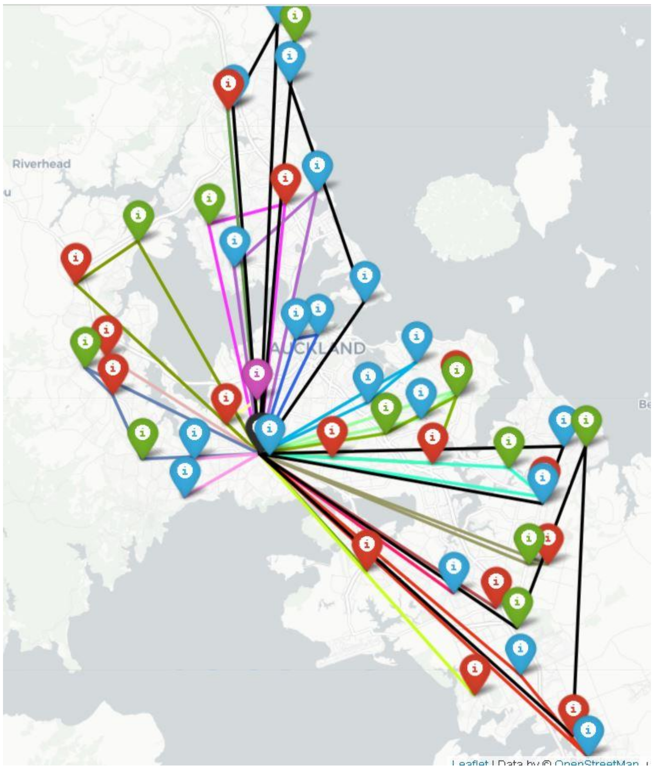
8.2 Appendix B. Visualisation of Routes during Weekdays. Foodstuffs Trucking Routes (left) and Mainfreight Trucking Routes (right).



8.3 Appendix C. Visualisation of Routes during Weekdays with One Map. Mainfreight truck routes are represented by black lines.

8.4 Appendix D. Visualisation of Routes during Saturdays. Foodstuffs Trucking Routes (left) and Mainfreight Trucking Routes (right).

8.5 Appendix E. Abstract Maps for Weekday Trucking Routes (left) and Saturday Trucking Routes (right). Mainfreight truck routes are represented by black lines.



8.6 Appendix F. Table of Traffic Multipliers.

Morning Shift	*Multiplier Interval (Random Uniformly Distributed)*
8:00am to 9:00am	[1.8,2.2]
9:00am to 10:00am	[0.9,1.1]
10:00am to 11:00am	[0.72,0.88]
11:00am to 12:00pm	[0.9,1.1]
Afternoon Shift	*Multiplier Interval (Random Uniformly Distributed)*
2:00pm to 3:00pm	[0.99,1.21]
3:00pm to 4:00pm	[1.125,1.375]
4:00pm to 5:00pm	[1.575,1.925]
5:00pm to 6:00pm	[2.025,2.475]

8.7 Appendix G. Demand Probabilities for a couple Stores.

	A	B	C	D	E	F	G	H
1		Weekend Pallet Probabilities						
2	**Supermarket**	***0***	***1***	***2***	***3***	***4***	***5***	***6***
3	Four Square BKs Torbay	0.5	0.5	0	0	0	0	0
4	Four Square Botany Junction	0.5	0.5	0	0	0	0	0
5	Four Square Cockle Bay	0.75	0.25	0	0	0	0	0
6	Four Square Ellerslie	0.5	0.5	0	0	0	0	0
7	Four Square Everglade	0.25	0.75	0	0	0	0	0
8	Four Square Fair Price Henderson	0.75	0.25	0	0	0	0	0
9	Four Square Glen Eden	0.75	0.25	0	0	0	0	0
10	Four Square Great Eastern	0.75	0.25	0	0	0	0	0
11	Four Square Hobsonville	0.5	0.5	0	0	0	0	0
12	Four Square Lancaster	0.75	0.25	0	0	0	0	0
13	Four Square Pakuranga Heights	0.5	0.5	0	0	0	0	0
14	Fresh Collective Alberton	0.25	0.75	0	0	0	0	0
15	New World Albany	0	0.25	0.5	0.25	0	0	0
16	New World Birkenhead	0	0.25	0.5	0.25	0	0	0
17	New World Botany	0	0.25	0.5	0.25	0	0	0
18	New World Browns Bay	0	0.5	0.5	0	0	0	0
19	New World Devonport	0	0.25	0.5	0.25	0	0	0
20	New World Eastridge	0	0	0.75	0.25	0	0	0
21	New World Green Bay	0	0.75	0	0.25	0	0	0
22	New World Howick	0	0.5	0.25	0.25	0	0	0
23	New World Long Bay	0	0.25	0	0.75	0	0	0
24	New World Metro Queen St	0	0.25	0.5	0.25	0	0	0
25	New World Milford	0	0	0.75	0.25	0	0	0

8.8 Appendix H. Outputs of the optimal solutions for weekday and Saturday linear programs.

Weekdays, Status: Optimal

Foodstuffs Truck Routes:
route: Warehouse -> Four Square Lancaster -> Pak 'n Save Wairau Road -> Warehouse
route: Warehouse -> Fresh Collective Alberton -> Pak 'n Save Mt Albert -> Warehouse
route: Warehouse -> New World Eastridge -> New World Remuera -> Warehouse
route: Warehouse -> New World Mt Roskill -> Pak 'n Save Royal Oak -> Warehouse
route: Warehouse -> New World Victoria Park -> New World Metro Queen St -> Warehouse
route: Warehouse -> Pak 'n Save Ormiston -> Four Square Botany Junction -> Warehouse
route: Warehouse -> Pak 'n Save Glen Innes -> New World Stonefields -> Warehouse
route: Warehouse -> Pak 'n Save Manukau -> Warehouse
route: Warehouse -> Pak 'n Save Sylvia Park -> Four Square Great Eastern -> Four Square Ellerslie -> Warehouse
route: Warehouse -> Pak 'n Save Westgate -> Four Square Hobsonville -> Warehouse
route: Warehouse -> Pak 'n Save Lincoln Road -> Warehouse
route: Warehouse -> Four Square Fair Price Henderson -> Pak 'n Save Henderson -> Four Square Glen Eden -> Warehouse
route: Warehouse -> Pak 'n Save Mangere -> Warehouse
route: Warehouse -> New World New Lynn -> New World Green Bay -> Warehouse
route: Warehouse -> Pak 'n Save Clendon -> Warehouse
route: Warehouse -> New World Papatoetoe -> Warehouse
route: Warehouse -> New World Papakura -> New World Southmall -> Warehouse

route: Warehouse -> Four Square Pakuranga Heights -> Pak 'n Save Botany -> Warehouse
route: Warehouse -> Pak 'n Save Albany -> Warehouse
route: Warehouse -> New World Birkenhead -> New World Milford -> Warehouse

Mainfreight Routes:
route: Warehouse -> Pak 'n Save Papakura -> Four Square Cockle Bay -> Four Square Everglade -> Warehouse
route: Warehouse -> New World Long Bay -> New World Albany -> Warehouse
route: Warehouse -> New World Howick -> New World Botany -> Warehouse
route: Warehouse -> Four Square BKs Torbay -> New World Browns Bay -> New World Devonport -> Warehouse

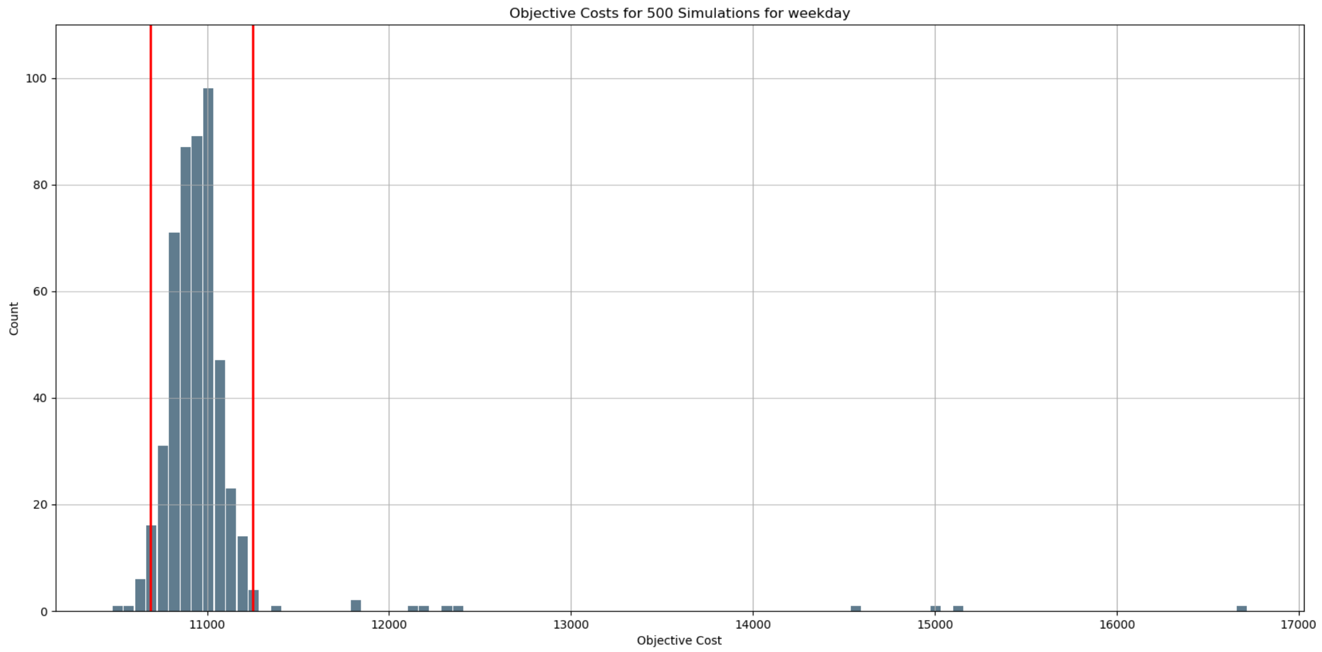
Shipping Costs: $10123.47 per day

Saturday, Status: Optimal

FoodStuffs Truck Routes:
route: Warehouse -> New World Papakura -> Pak 'n Save Papakura -> New World Southmall -> Pak 'n Save Clendon -> Warehouse
route: Warehouse -> New World Botany -> Pak 'n Save Ormiston -> Four Square Botany Junction -> Four Square Everglade -> Warehouse
route: Warehouse -> Four Square Pakuranga Heights -> New World Howick -> Four Square Cockle Bay -> Pak 'n Save Botany -> Warehouse
route: Warehouse -> Pak 'n Save Wairau Road -> New World Milford -> New World Devonport -> Warehouse
route: Warehouse -> Fresh Collective Alberton -> New World Victoria Park -> New World Metro Queen St -> Pak 'n Save Mt Albert -> Warehouse
route: Warehouse -> New World Mt Roskill -> Warehouse
route: Warehouse -> New World Birkenhead -> Four Square Lancaster -> Pak 'n Save Albany -> New World Albany -> Warehouse
route: Warehouse -> Pak 'n Save Royal Oak -> Four Square Ellerslie -> New World Stonefields -> New World Remuera -> Warehouse
route: Warehouse -> Pak 'n Save Sylvia Park -> Four Square Great Eastern -> Pak 'n Save Glen Innes -> New World Eastridge -> Warehouse
route: Warehouse -> Four Square Fair Price Henderson -> Pak 'n Save Lincoln Road -> Pak 'n Save Westgate -> Four Square Hobsonville -> Warehouse
route: Warehouse -> New World Green Bay -> Four Square Glen Eden -> Pak 'n Save Henderson -> New World New Lynn -> Warehouse
route: Warehouse -> New World Long Bay -> Four Square BKs Torbay -> New World Browns Bay -> Warehouse
route: Warehouse -> Pak 'n Save Manukau -> New World Papatoetoe -> Pak 'n Save Mangere -> Warehouse

Shipping Costs: $ 5387.99 per day

8.9 Appendix I. Histogram of Weekday Route Objective Costs for 500 Simulations.



8.10 Appendix J. Histogram of Saturday Route Objective Costs for 500 Simulations.