Truck Scheduling for Food stuffs

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1. Data Analysis

Foodstuffs has provided us with the following data to assist in modelling the problem:

- demandData.csv – Number of pallets delivered to each Foodstuffs store over a four-week span
- FoodstuffLocations.csv – The GPS coordinates of each store
- FoodstuffDistances.csv – The travel distance between each store
- FoodstuffTravelTimes.csv – The mean travel time between each store

To analyse the given data, we plotted a bar graph of the pallet demands from all stores over 4 weeks to better understand the overall trends in daily demands throughout the week. We then plotted the pallet demands from a couple individual stores to get a sense of the variation from store to store, shown in Fig. 1.

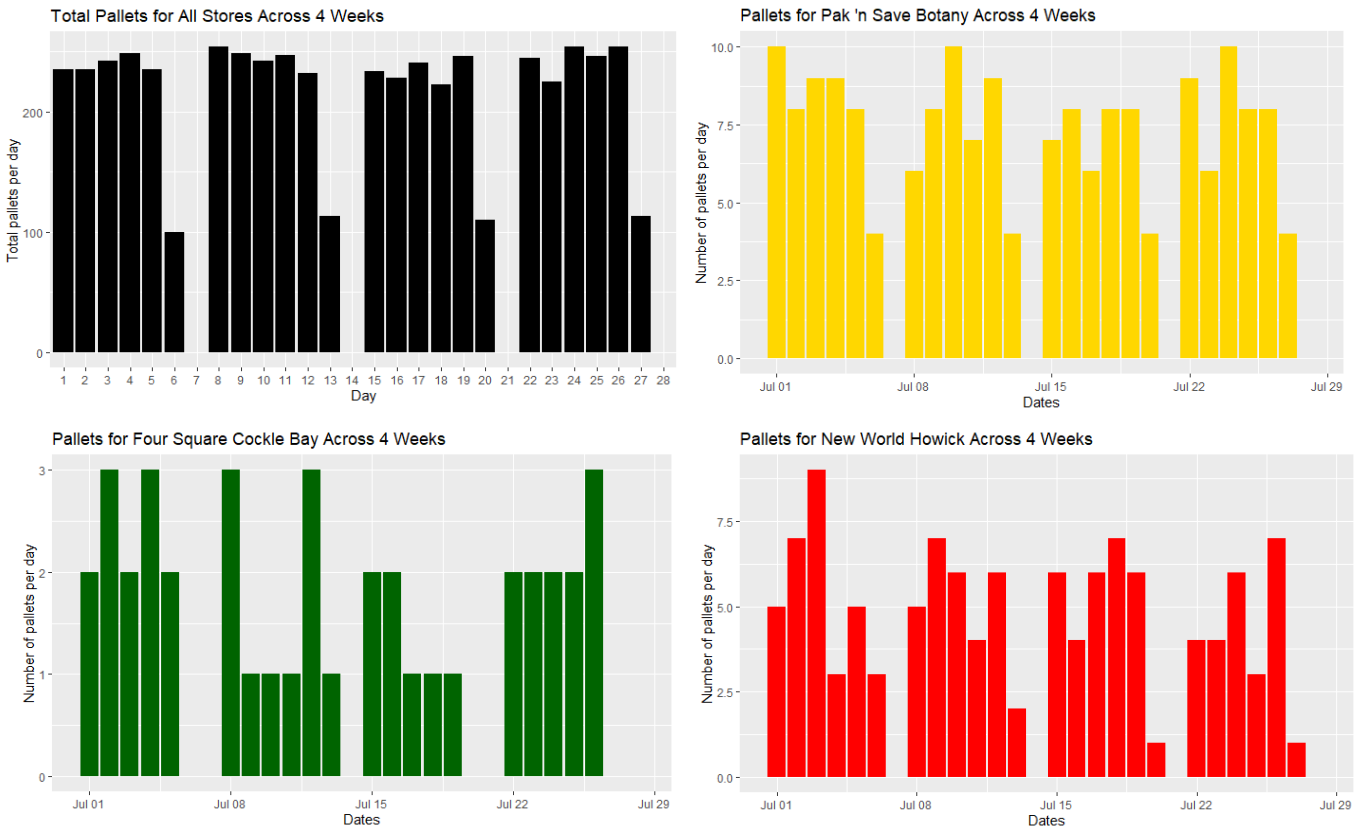

Figure 1. (top left) Total pallets for all stores across the four-week span. (top right) Pallets for Pak 'n Save Botany across four-week span. (bottom left) Pallets for Four Square Cockle Bay across four-week span. (bottom right) Pallets for New World Howick across four-week span.

We see the daily weekday demands to be roughly constant throughout the week, with a mean of around 230 pallets per day. There is a decreased demand on Saturdays, with around half of the pallets demanded on a Saturday than on a typical weekday. There is also no demand on Sundays across all stores.

Since Foodstuffs operates on four different types of supermarkets (Four Square, Fresh Collective, New World and Pak ‘n Save), it is natural to compare the demands between these types to see if there is any noteworthy trend. A boxplot visualising the daily pallet demands for each type of supermarket is shown in Fig. 2.

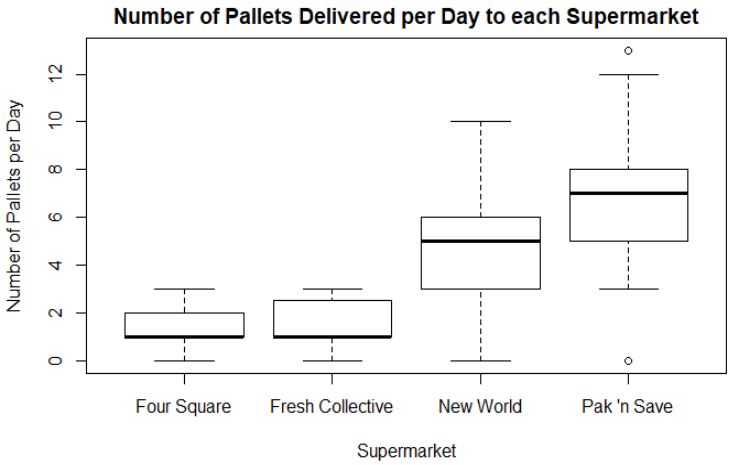

Figure 2. Number of pallets delivered per day for each type of supermarket per day

Pak ‘n Save supermarkets have the highest median number of pallets per day of 7 and largest range of 13. New World supermarkets have median number of pallets per day of 5 with a range of 10. The number of pallets per day for Four Square and Fresh Collective is 1, and both have a range of 3.

To clean the data, we had to remove any deliveries to supermarkets greater than 12 pallets as a single trip cannot carry more than 12 pallets. We also created an estimate pallet demand for each store for a weekday and for a Saturday, done by taking the median and rounding it up to the next integer.

In order to visualise the routing problem, the map of the stores was created with the Python ‘folium’ module and OpenStreetMap. The location data was given in the FoodstuffLocations.csv file.

Figure 3. Map of Foodstuffs supermarkets, split by region (North, West, Central and South-East) and colour-coded by type (Pak ‘n Save, Four Square, New World, Fresh Collective, Warehouse)

2. Route Generation

The stores were partitioned by subjective judgement into four different regions to reduce the number of generated routes to a workable size (Fig. 3). We assumed that trucks only delivered to supermarkets in that region during their route. To further simplify the problem, a few extra assumptions were made in addition to the ones mentioned in the problem brief, which are listed below:

- Both the Foodstuff and Mainfreight trucks may only complete one route (simple circuit starting and ending at the central distribution warehouse) for each four-hour shift.
- Mainfreight trucks may not operate longer than their designated four-hour shift.
- Foodstuff trucks may operate longer than their designated four-hour shift but are limited to an extra 30 minutes (a maximum of four and a half hours in total).
- Traffic conditions are ignored and the given median travel times are used.

The routes were generated by producing all the possible simple circuits starting and ending in the warehouse within each region. We did this by using a recursive method that keeps going down different paths until the path does not fulfill a condition or assumption (for example, if the path has a total demand of greater than 12 pallets). This algorithm works similar to 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 are 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. Optimisation Model Formulation

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 as follows:

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:

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

4. Results

The outputs of our optimal solutions for the weekday and Saturday linear programs are below:

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 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

We notice that during the weekdays, 20 routes were taken by normal trucks, and 4 were taken by Mainfreight ones. This resulted in a total cost of $10123.47 per day to ship all required pallets.

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

We notice that on Saturday, there were much less routes needed due to the decreased demand; 14 routes were taken by normal trucks and no Mainfreight ones were used. This resulted in a total cost of $5387.99 per day to ship all required pallets.