Surrey LRT
Optimal Station Locations

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1 Introduction

Over the next five to ten years, the City of Surrey is planning to build a Light Rail Transit (LRT) system comprised of two routes. The first route begins at Newton Exchange along King George Boulevard and continues to 104 Ave where it makes a right turn and terminates at 152 Street. The second route begins at King George Station and continues along Fraser Hwy until it terminates at Langley Centre. The Newton route is the first phase of the project and deliberations on this route have completed, the city plans to begin construction in 2019 pending funding [1]. The Fraser Hwy route is part of phase two and decisions about issues such as the placement of transit stops are ongoing.

Figure 1: Surrey LRT System Plan
Source: TransLink

The city has decided to build this LRT system in order to address the needs of a growing population. Over the next 30 years, the city expects Surrey's population to grow by 300,000 and an expanded transit system is necessary to meet this additional demand [2]. The city has identified a number of benefits beyond simply meeting demand, including protecting the environment and creating jobs in the region [3].

One of the key decisions that must be made before construction of the Fraser Hwy route is the placement of the transit stops. Placing stops requires balancing convenience, utilization, and costs. If too few stops are built, fewer people may use transit and some the benefits may not be fully realized. On the other hand, if too many stops are built, using the system may be more convenient for more people but there will be the risk that some stops are underused and, therefore, the cost of building and operating that particular stop may exceed the expected benefits.

In this paper, we use linear programming methods to determine the most efficient placement of transit stops along Fraser Hwy from King George Station to Langley Centre. The goal will be to minimize costs while extracting as much benefit as possible by balancing convenience and utilization of stations.

2 Background

The transit stop location problem is a long standing one which have historically been solved using a mixed integer approach. Sha Mamun of the University of Connecticut solves a multi-objective formulation of the problem as a mixed integer problem [4]. Mamun combines his formulation with a heuristic algorithms designed to speed up computation and provide close to optimal solutions. Combining a linear programming formulation of the problem with heuristic algorithms is typical for this problem. For example, researchers in Iran have combined the mixed integer programming approach with a genetic algorithm [5]. Other approaches are purely algorithmic such as research from Europe that uses a polynomial algorithm to determine optimal stops for realistic travel times [6].

Due to time and resource constraints we will be approaching this problem from a more simplified perspective using a purely binary formulation. We propose that this approach, while not entirely comprehensive, provides realistic approximations of the considerations real planners have to think about. The general consideration being where to place stations such that none are underused and costs/benefits are optimized.

Binary models have application beyond transit stops. Generalizing the problem to an overall placement problem, one can think about optimal placements of ATMs, street lights, or gas stations by analyzing different sets of constraints. But applications are broader than placing objects in a geography. Binary model can be used to assigning tasks to people such as assigning cases to lawyers [7]. They can also be used to solve networking problems where each node in a network is binary decision variable [8].

3 Model Overview

Our model is a binary model where the decision variables correspond to intersections along Fraser Hwy from King George Station to Langley Centre. Each decision variable is assigned a cost determined by the sum of the costs for each station minus the sum of the benefits. The benefits are factor of population density and civic/commercial density.

The constraints include stations which are mandatory, minimum distances between stops, and demand considerations.

4 Assumptions

To simplify our model and to allow us to complete the project within our time and resource constraints we need to make general assumptions.

These assumptions are:

- The costs and benefits are uniform for each transit stop. The total costs and benefits over 30 years for the whole system were divided by the total number of projected stations to derive a constant cost/benefit per station.
- The Newton-King George route is a good approximation of TransLink's priorities and can be taken as a guideline for priorities along the Langley route.
- The percentage of the population who will be transit users is uniform along the entire route.
- The Surrey-Langley LRT will offer service alongside Bus Rapid Transit on Fraser Highway, rather than replace buses.
- Future bus routing/scheduling will remain the same as the existing service, as there is no reliable way to predict future service changes by Translink.

5 Constraints

5.1 Population

The population is an important factor to indicate the demand from residents living around each intersection and to estimate the benefits from the demand. We used software called Population Explorer to measure the population for each intersection. Population Explorer is software produced by Oakridge National Laboratories in Tennessee to estimate the human population of an area using census data, road networks, satellite imagery and proximity to coastlines, land use, slope, and elevation [10]. This software is capable of measuring the number of people living within a user defined radius on each intersection.

According to our research, 27 percent of people living within 800 meters use transit and only 7 percent of people use transit between 800 meters and 4 km [9]. Therefore, we gathered population data of people living within 1 km and 4 km and multiplied them by the ratios 0.27 and 0.07 to find the total population of transit users.

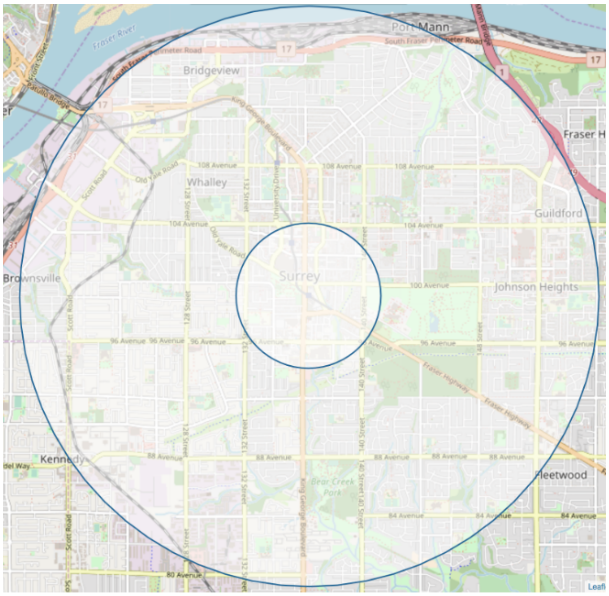

Figure 2: 1 km and 4 km radius around King George Station using Population Explorer

We also applied a penalty to each intersection depending on the size of the population, so that intersections with less population receive fewer benefits compared to the high population intersection which receive the full benefit. According to the evaluation report from TransLink, the estimated total transit user benefit over 30 years is $39,052,632 for each station. We decided to apply this full benefit if the intersection has more than or equal to 10,000 population. If the intersection has less than 10,000 population, the penalty is applied to the benefit by multiplying it by the ratio (population/10,000).

Let:

h_i be the total population who use transit at intersection i

P_i be the penalty ratio depending on population size at intersection i

$$P_i = \begin{cases} 1 & \text{if } h_i \geq 10{,}000 \\ \frac{h_i}{10{,}000} & \text{if } h_i \leq 10{,}000 \end{cases}$$

Then, the total benefits associated with an intersection's population is:

$$\sum_i x_i P_i \cdot (39{,}052{,}632)$$

5.2 Demand

Another important factor to determine the allocation of LRT stations is the demand at each intersection by transit users. To compute the level of demand, we calculated the ratios between the number of transit users and the number of buses that serve the intersection. The ratio is an indicator of how efficiently these stations are being used. A greater ratio represents higher demand.

The data that we used for this constraint is the populations of each intersection within a 1km radius and the total number of buses that stop at the intersection each week. By dividing the number of transit takers within the radius by the number of buses that serve this station, we can obtain the ratios. We let r_i denote the ratio at potential station i.

After generating these ratios, we compared them with the highest and the average ratios of phase one of the LRT project, which starts from Newton Exchange and terminates at Guildford Exchange. The ratios of the other line are calculated using the same method with the stations predetermined by TransLink and the City of Surrey.

We think it is necessary for the two section of the LRT system to match each other in terms of serving rate. Additionally, with a goal of minimizing the cost, we prefer the stations to be used as efficiently as possible to avoid extra construction costs and revenue loss.

We determined the average people to bus ratio of the Newton Guildford line as 8 people/bus; this means that for every bus that stops at a station on the line, it picks up 8 people on average. At Guildford Exchange, the people-bus ratio is 12, which is the highest on this line.

In order to minimize cost while also meeting demand, we limited our choices on selecting the stations. First, we consider the intersection to be a potential station if the people to bus ratio is greater than or equal to the highest ratio of the other line. The resulting ratios show that stations should be built at Whalley, Fraser Highway at 196 Street and Fraser Highway at 200 Street.

However, only satisfying the highest demands might not be enough to match the serving rate of the other line. Therefore, for the second part of the constraint we require the sum of ratios of selected stations to be greater than or equal to the sum of people that the other line serves, and each bus on the other line serves approximately 70 people.

5.3 Mandatory Stations

5.3.1 Terminus Stations

In accordance with Surrey LRT's publicly released project details, the two terminus stations will be King George Station and Langley Centre at 203 Street. This means that the decision variables for these two intersections must indicate that both will have a station located there.

$$\text{Terminus Station King George: } x_1 \geq 1$$

$$\text{Terminus Station Langley Centre: } x_{18} \geq 1$$

5.3.2 Town Covering

Four towns/communities are situated directly on the path of the Surrey-Langley Line: City Centre, Whalley, Fleetwood, and Cloverdale.

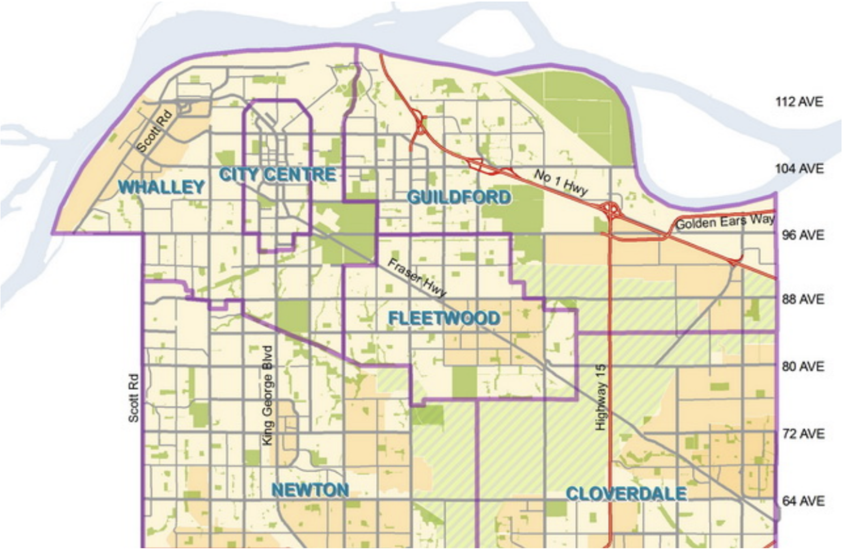

Figure 3: Town Divisions in Surrey
Source: https://fraseropolis.com

The locations of these communities and their respective town centres are likely to be reflective of population distribution and density, as well as areas of interest. This information can be used to help inform the distribution of transit stations. A basic goal of the LRT is to effectively service the communities in the immediate vicinity, so there should be at least 2 stations located within the boundaries of each community on the LRT path. Having at least 2 stations (rather than at least 1) helps increase the chance that each community will be adequately covered. Constraints can be formulated based on the communities that each intersection falls within:

$$\text{City Centre: } \sum x_i \geq 1, i = 1,2,3$$

$$\text{Whalley: } \sum x_i \geq 1, i = 3,4,5$$

$$\text{Fleetwood::} \sum x_i \geq 1, i = 5,\ldots,12$$

$$\text{Cloverdale:} \sum x_i \geq 1, i = 12,\ldots,18$$

Note that the intersections that lie on the community boundaries are treated as belonging to both. These intersections are x_3 , x_5 , x_{12} , or 140 St, 148 St, and 176 St respectively.

5.3.3 Willowbrook Shopping Centre

The Langley (Cloverdale) area along the Fraser Highway route tends to be less dense as development is more spread out. In combination with the large open spaces occupied by Willowbrook Shopping Centre parking lots, this lower density could lead to a significant negative impact on the suitability of the adjacent intersections. However, the mall and its surrounding businesses are the major economic centre and destination for mall-goers in the area so there should be a station nearby to address that demand. A constraint can be created to ensure that there is indeed a station adjacent to the mall, just in case the low urban density skews the linear program from placing a station there.

$$\text{Willowbrook Centre:} \sum x_i \geq 1, i = 14,15,16$$

5.4 Distances Between Stops

5.4.1 Bracketing

Applying the same assumption used for population counts that a physical station intrinsically provides service coverage for a 4 km range, we would want to ensure that the LRT system does not have any dead zones (no service available) along the route.

Acknowledging that the likelihood of a person using the LRT declines the farther they are from a station, we can reduce the maximum distance between stations to increase coverage and have stations closer to more people.

Thus a constraint can be made that for every 4 km of LRT route, there is at least one station. This effectively ensures that people along the route are at most 2 km away from the nearest station, and that people not along the route are more likely to be closer to a station.

This can be done in the program constraints by evaluating every 4 km segment originating from a node (intersection) and having a greater-or-equal to 1 constraint.

$$\begin{array}{lll} Brackets & \sum_{i=1}^{5} x_i \geq 1 & \sum_{i=8}^{11} x_i \geq 1 \\ & \sum_{i=2}^{6} x_i \geq 1 & \sum_{i=9}^{12} x_i \geq 1 \\ & \sum_{i=3}^{8} x_i \geq 1 & \sum_{i=10}^{12} x_i \geq 1 \\ & \sum_{i=4}^{8} x_i \geq 1 & \sum_{i=11}^{13} x_i \geq 1 \\ & \sum_{i=5}^{10} x_i \geq 1 & \sum_{i=12}^{14} x_i \geq 1 \\ & \sum_{i=6}^{11} x_i \geq 1 & \sum_{i=13}^{17} x_i \geq 1 \\ & \sum_{i=7}^{11} x_i \geq 1 & \sum_{i=14}^{18} x_i \geq 1 \end{array}$$

5.4.2 Buffer Zone

To prevent the linear program from placing all of the stations next to one another at the densest areas (since population, demand, and business density tend to be highest near intersections with dense development) and to encourage a more even distribution of stations, we introduced a buffer zone in the linear program.

The buffer zone is a 1.5 km diameter no-build zone around a station that prevents another station from being built within the zone. We decided to base the buffer zone on Translink's average station spacing distance rather than the adjacency of nodes (intersections) because the distance between each intersection is different (some are close, some are far apart), so a physical solution would be more suitable for ensuring that stations are not too geographically close to each other.

$$Buffer \quad \sum_{i=2}^{3} x_i \le 1 \quad x_9 \le 1$$
$$\sum_{i=2}^{4} x_i \le 1 \quad x_{10} \le 1$$
$$\sum_{i=3}^{4} x_i \le 1 \quad x_{11} \le 1$$
$$x_5 \le 1 \quad x_{12} \le 1$$
$$\sum_{i=6}^{7} x_i \le 1 \quad x_{13} \le 1$$
$$\sum_{i=6}^{8} x_i \le 1 \quad x_{14} \le 1$$
$$\sum_{i=7}^{8} x_i \le 1 \quad \sum_{i=15}^{16} x_i \le 1$$
$$\sum_{i=15}^{17} x_i \le 1$$
$$\sum_{i=16}^{18} x_i \le 1$$

An exception was made to not include the two terminus stations, King George and Langley Centre, in the buffer zone constraint because those two stations are forced and their buffer zones are too restrictive as they would effectively remove several nearby intersections from consideration entirely.

5.4.3 Travel Time

In order for the LRT to be a competitive and viable commute option for riders, it needs to service enough stations at different locations to reach a large population without creating a situation in which it takes too long to travel from one end to the other. Limiting the total trip time as a constraint focuses on the latter aspect by ensuring that a trip on the LRT takes either the same amount of time or shorter when compared to the same trip made via other transit options.

Here we follow the assumption that future traffic patterns on Fraser Highway and Translink bus scheduling on this route remains exactly the same for 30 years. One-way trip times for the two bus routes (502 and 503) that share the same path as the proposed LRT during regular hours of operation was collected using Google Maps and Translink's app and weighted according to traffic volume data at the respective hours to find a weighted average trip time [11].

	Car (low)	Car (mean)	Car (high)	Bus 502	Bus 503
Raw Avg Trip Time (mins)	21.92	30.23	38.54	47.74	40.72
Weighted Avg Trip Time (mins)	22.13	33.86	45.60	50.90	41.84

The 502 route stops much more frequently than the 503, which is an express route. An LRT would occupy a role more similar to that of the express bus route, so the group will evaluate LRT trip times against the 503. Given that having an equal or lesser trip time than the 503 would be faster than the trip made by car during high traffic volume hours, we find this to be a reasonable benchmark for the LRT.

Surrey LRT's reported an average LRT speed of 33.8 kmph (not including stopping) means that it would take the LRT a base time of 28.36 minutes to travel the 15.975 km route [12]. According to a study on New York's subway system, making each stop (decelerating and accelerating) at a station adds on 1 minute compared to bypassing the station [13]. Accounting for the time that a train remains at a stop (20 seconds according to the same study), each additional station that we add to the Surrey LRT would increase total trip time by 1.333 minutes. Though the two transit systems are not the same, we will assume the LRT has the same operation delay since there is a lack of available data on the LRT. This leads to the constraint:

[number of stations] * [1.333 mins] + [base trip time, mins] <= [time to beat]

or

$$\text{Max Trip Time: } \sum_{i=1}^{18} x_i \leq \frac{(41.84 - 28.36)}{1.333}$$

6 Objective Function

Our objective is to minimize the cost of transit stops. The total cost is equal to the sum of the construction and operation costs minus the benefits generated by selecting ideal stations with respect to population density and where the concentration of businesses is high.

TransLink provides data on construction and operation costs of their stations which is what the costs/benefits in the objective function are based [14]. To minimize the cost, we first need to determine where the stations are placed. Let x_i denote whether a LRT station is built at intersection i.

$$x_i = \begin{cases} 1 & \text{if a station is built at intersection } i \\ 1 & \text{otherwise} \end{cases}$$

For each selected station, the cost is comprised of a construction fee of $75,052,632 and an operations fee of $13,947,368 each over a 30-year period. Therefore, the total expense of building the transit stops can be expressed as:

$$\sum_i x_i \cdot (75{,}052{,}632 + 13{,}947{,}368)$$

If the allocation of stations is optimized, the benefits provided by the stations ought to be higher. For example, if a station is built at an intersection where the business concentration is high, the tax and wage revenues will increase for city of Surrey. We have evaluated the commercial density of each intersection based on numbers of businesses, schools and public spaces in the neighborhood.

Business density scores range from 2 to 21 in our evaluation. For example, King George station has a business density score of 21 because it is close to Surrey Central mall, SFU Surrey campus, and other attractions, whereas Fraser Highway at 148 Street has a score of 2 because there are few attractions there.

If a station is located at an intersection which has a score that is greater than or equal to 10, this will be an ideal choice, and it will provide full benefit. However, for the stations that are placed in less dense areas, the benefit would reduce linearly corresponding to their density scores. For example, if an intersection has a density score of 2, the benefit generated would be reduced to 0.2 of the full benefit. Let p_{ai} represent the percentage of benefit that station i will achieve.

In our model, we consider two long-term benefits, which we refer to as attraction benefit and travel benefit. The attraction benefit is generated from tax and wage revenues, and the travel benefit includes fare revenues, travel time savings, auto operating cost savings, collision cost savings and GHG emission reductions. The attraction benefit per station over a 30-year period is $47,947,368 and the travel benefit is $39,052,632.

Similarly, if the population around an intersection is high, a station that is built at that intersection would potentially serve more people and provide more travel benefit. If the population around an intersection is less than 10,000, the travel benefit would reduce linearly corresponding to their population. We let p_{ti} denote the percentage of travel benefit generated at intersection i.

Therefore, the total benefit of constructing the transit stops over a 30-year period can be represented as:

$$\sum_i x_i [p_{ai} \cdot 47{,}947{,}368 + p_{ti} \cdot 39{,}052{,}632)]$$

The objective function is:

$$\sum_i x_i \cdot (75{,}052{,}632 + 13{,}947{,}368) - \sum_i x_i [p_{ai} \cdot 47{,}947{,}368 + p_{ti} \cdot 39{,}052{,}632)]$$

Together, we define our objective function and constraints to be:

Minimize

$$\sum_i x_i \cdot (75{,}052{,}632 + 13{,}947{,}368) - \sum_i x_i [p_{ai} \cdot 47{,}947{,}368 + p_{ti} \cdot 39{,}052{,}632)]$$

Subject to

$$
\begin{aligned}
&\textit{Terminus Stations} && x_1 = 1 && \textit{Demand} && x_2 \leq 1 \\
& && x_{18} = 1 && && x_{15} \leq 1 \\
& && && && x_{17} \leq 1 \\
& && && && \sum_i x_i r_i \geq 70
\end{aligned}
$$

$$
\begin{aligned}
&\textit{Town Coverage} && \sum_{i=1}^{3} x_i \geq 2 && \textit{Max Trip Time} && \sum_{i=1}^{18} x_i \leq \frac{41.84 - 28.36}{1.333} \\
& && \sum_{i=3}^{5} x_i \geq 2 \\
& && \sum_{i=5}^{12} x_i \geq 2 \\
& && \sum_{i=12}^{18} x_i \geq 2
\end{aligned}
$$

$$
\begin{aligned}
&\textit{Buffer} && \sum_{i=2}^{3} x_i \leq 1 && x_9 \leq 1 \\
& && \sum_{i=2}^{4} x_i \leq 1 && x_{10} \leq 1 \\
& && \sum_{i=3}^{4} x_i \leq 1 && x_{11} \leq 1 \\
& && x_5 \leq 1 && x_{12} \leq 1 \\
& && \sum_{i=6}^{7} x_i \leq 1 && x_{13} \leq 1 \\
& && \sum_{i=6}^{8} x_i \leq 1 && x_{14} \leq 1 \\
& && \sum_{i=7}^{8} x_i \leq 1 && \sum_{i=15}^{16} x_i \leq 1 \\
& && && \sum_{i=15}^{17} x_i \leq 1 \\
& && && \sum_{i=16}^{18} x_i \leq 1
\end{aligned}
$$

$$Brackets \qquad \sum_{i=1}^{5} x_i \geq 1 \qquad \sum_{i=8}^{11} x_i \geq 1$$
$$\sum_{i=2}^{6} x_i \geq 1 \qquad \sum_{i=9}^{12} x_i \geq 1$$
$$\sum_{i=3}^{8} x_i \geq 1 \qquad \sum_{i=10}^{12} x_i \geq 1$$
$$\sum_{i=4}^{8} x_i \geq 1 \qquad \sum_{i=11}^{13} x_i \geq 1$$
$$\sum_{i=5}^{10} x_i \geq 1 \qquad \sum_{i=12}^{14} x_i \geq 1$$
$$\sum_{i=6}^{11} x_i \geq 1 \qquad \sum_{i=13}^{17} x_i \geq 1$$
$$\sum_{i=7}^{11} x_i \geq 1 \qquad \sum_{i=14}^{18} x_i \geq 1$$

Alternatively, if we focus more on covering greater population, the following constraint would also be included:

$$population \quad coverage \qquad \sum_i x_i h_i \geq \frac{1}{2} \sum_i h_i$$

With this constraint they stations will be within service range of at least half of the total populations.

7 Results

Using Solver in Excel, we were able to find an optimal solution providing all the locations, costs, and benefits over 30 years. We determined that 7 stations were optimal with a minimized total cost of $179,826,284.2. Although it succeeded to minimize the cost and find the optimized locations for stations, the population coverage was less than half of the total population. This could be a potential problem in meeting sufficient demand for the residents in the community.

Hence, we constructed a new model with one additional constraint that stations should be accessible to at least half of the population. This time the optimal solution provided included two stations additional stations to our previous solution. In this new model, the population coverage has increased significantly by 13,481 which is 9 percent of the total population. However, the cost was increased by $24,663,673.7 which may be reasonable for a project of this size.

Figure 4: Optimal Locations for the First Model (Green) and the Second Model (Green and Red)

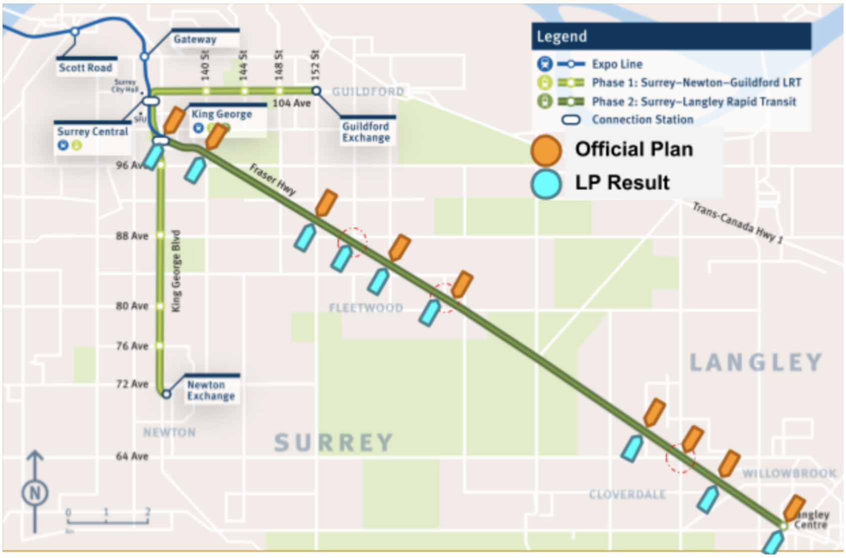

Figure 5: Comparison between Official LRT Plan and Linear Program Result

8 Conclusion

Our result is similar to the officially released plan (which was updated onto Surrey LRT's website after we began the project). From this we may be able to draw a conclusion that we have indeed identified the major priorities for the LRT and the most significant considerations that go into Translink's decision-making for locating LRT stops - population/ridership, businesses, and demand. There also tends to be correlation between these factors, as the more populous locations tend to have more businesses and bus routes, so it makes sense that the intersections with the highest attraction and ridership would be selected for a LRT station. While the factors taken into account and their respective influence on the linear program are not an exact match with Translink's model, the similarities between their plan and our approximations suggest that our other considerations for travel time, station distribution, coverage, and cost are probably consistent with or reflective of Translink's priorities and goals for the Surrey LRT.

	King George	Whalley	140 St	96 Ave	148 St	152 St	88 Ave	156 St	160 St	164 St	168 St	176 St	184 St	64 Ave	196 St	Langley Bypass	200 St	Langley Centre	# of Stations
Surrey LRT Official Plan	1		1			1			1	0.5	0.5		1	1	1			1	9
*according to Surrey LRT website: 0.5 stations is because they opted for a minor intersection between 164st and 168st, which we did not consider as it was a 'T' interse																			
Final Result	1		1		1	1			1	1			1		1			1	9
*as is																			

Figure 6: Spreadsheet comparison between Official LRT Plan and Linear Program Result

One discrepancy that exists between the official plan and our optimization result occurs near the midpoint of the route, between the 164th and 166th locations. The first reason for this discrepancy is that we had not considered the 166th intersection in our linear program; it is a minor intersection between Fraser Highway and a 200m street that connects two parking lots. However, even if we had included 166th in our set of possible intersections to consider, it would likely not score very well in attraction, population, or demand especially when compared to the two adjacent intersections of 164th and 168th.

Translink may have selected this small intersection for a LRT station over its neighboring options for two major reasons:

A. 166th is right next to the Surrey Sports and Leisure Complex (SSLC), which they have identified as the largest major attraction in the area. Our linear program considered both 164th and 168th as being close enough to the SSLC to have it count towards their economic benefit scores, and realistically it is a short walk from either of the two major intersections. However Translink probably found that having a station dedicated to the SSLC would be more beneficial as well as being able to cover for the population overlap between 164th and 168th.

B. Translink probably has data on future developments in the area and knows that 166th will become a more important intersection than it currently is. Unlike the project scope here, they are likely to also have considered how accommodating to an on-street LRT station each location is. 164th currently has several new developments at the intersection and it is not feasible to demolish them in the near future to make room for a station. The 168 St is a busy intersection with higher traffic speeds which may make it more difficult to integrate a station at that intersection. 166th, however, has undeveloped land around the intersection and it would be easier to facilitate construction there.

The second discrepancy between the plans is that we placed a station at 148th in Fleetwood while Translink put it at 64th in Cloverdale. The latter is the slightly denser of the two in terms of population and business density within 1 km the intersection, however 148th has a significantly higher population at the 4 km range as well as having many more buses stop at the intersection itself.

Despite initially appearing slightly less attractive in the immediate vicinity of the intersection itself, 148th was evaluated by the linear program to have a much higher travel benefit due to having double the ridership at 4 km, which lowered cost through increased travel benefit.

From Translink's perspective, the people closer to the station could be weighted as even more important than our analysis, and those further away as less important than in the linear program. They may also have considered the Cloverdale location over the Fleetwood location to have a more even distribution along the entire route, or perhaps because Cloverdale is expected to have more growth over time that having a station at 64th will be better in the long run. Another aspect that may have influenced their decision is that a lack of buses at an intersection is an opportunity to increase service using an LRT, or perhaps Translink is planning to have increased bus service there in the future. On the other hand the linear program modeled bus frequency as a representation of transfer demand at an intersection, which is why 148 was a more suitable choice based on the existing bus network.

9 Recommendations

While the model used in the linear program reasonably accounted for the major factors that determine the suitability of an intersection, there is room to make the model more comprehensive. The following are considerations that were left out of the project scope, either due to lack of available data or a significant increase in the complexity of evaluating it quantitatively: the physical/geographic suitability of locations for development, accounting for future changes to development or traffic patterns, and more focus on an priority areas and an even distribution of stations.

Of course more relevant data would have made the model more accurate as well. For example having access to travel speed and stopping data for the LRT would make for a more accurate travel time evaluation rather than using data from the New York subway network. Further, a more detailed analysis and quantification of business benefits as a result of a nearby LRT station would make the attraction benefit much more reflective of current and future system benefits.

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