Burnaby Mountain Gondola Study

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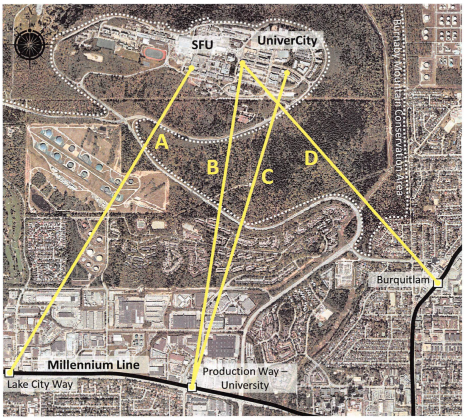
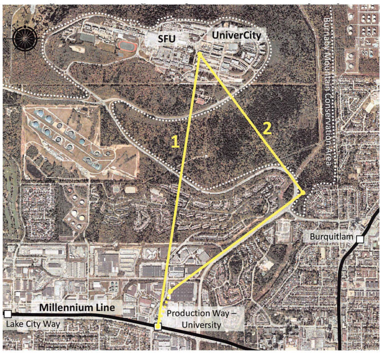
1 Introduction

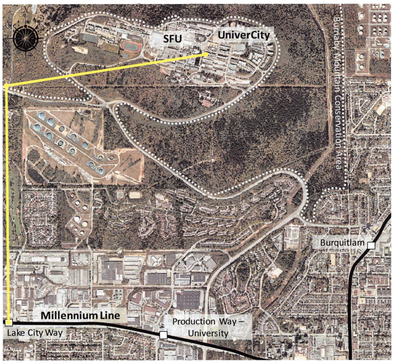
Every winter, Vancouver is faced with heavy snowfall which has been resulting in transit delays, university closures, missed work and classes. This has specially impacted the students of Simon Fraser University (SFU). Due to its location on the mountain, it receives heavier snowfall compared to the rest of the city. For almost a decade now, TransLink has been trying to address this issue in order to avoid halting normal operations of the university during snow. A TransLink study conducted in 2011 suggested a 120 million dollar gondola transit line to be built which would connect the mountain to the city when transit is not operational during snow [5].

This gondola would not only allow normal operation during winter but cut the transit time in half. Each gondola would be able to carry roughly 25 people to SFU within 6 minutes and would depart every 30 seconds. With 25,000 riders transiting to and from SFU every weekday, not only would a gondola help during the harsh winter snow, but also during the peak hours in any other season. This project is going to study some alternative routes for the gondola project and would assess passenger demand, time restriction and operation and maintenance cost for each route. By 2030, the proposed Burnaby Mountain Gondola Transit Project would be used by over 60000 people including students, faculty as well as residents of UniverCity.

Due to lack of funding and support in 2011 this project has been postponed which caused the capital and operating costs to increase due to inflation from property tax. The capital cost has been adjusted to $ 193 million for an 18-month construction period, less the reclaimed transit capital cost value of $ 34.5 million is $ 158.5 million. The transit operating cost of the gondola is $ 54.2 million, way less than the bus operating costs of $ 89.3 million. Summing the capital and operating costs, we get a total of $ 123.4 million [1].







2 Problem

Implementing a gondola route that would meet a demand of 25,000 transit users per day, while minimizing the Operations and Maintenance cost for a combination of gondola and bus routes. Therefore, we have to implement a gondola route that would also decrease the number of bus route operations adjacent to the gondola, as bus operation has increased costs associated. The cost and time constraint are also important factors to be considered while implementing a combination of bus and gondola routes. We could have the following three options when considering both time and cost constraints. Is it more cost and time efficient to run:

1. Multiple gondolas and no bus routes
2. A mixture of buses and gondolas
3. All buses and no gondolas

Next step would be to decide the number of gondolas that should run at each (peak or non-peak) hour, in coordination with the usual bus routes 144, 145, 143 and R5. As well as, if we decide to increase the operation of gondolas, we would have to simultaneously decrease the number of buses leaving the station to balance the cost.

3 Data

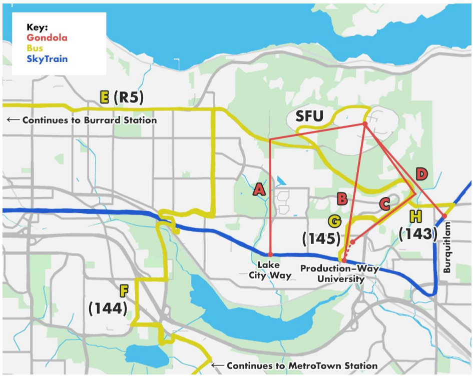


Figure 1: Gondola Route Options and Current Bus Routes

3.1 Gondola Routes

A total of six gondola routes have been placed under consideration since the 2009 Initial Feasibility Study. Of these six routes, we have chosen four for our project. Of the two gondola routes we've excluded from our project, one posed a severe safety concern and was dismissed completely, and the other terminated further east from the SFU transit exchange, an unideal location for SFU passengers [6]. Figure 1 demonstrates the four remaining gondola routes: A, B, C and D.

3.2 Bus Routes

There are a total of five bus routes that terminate at the SFU exchange; 145, departing from Production–Way University Station, 143, departing from Burquitlam Station, 144, departing from Metrotown Station, R5, departing from Burrard Station and N35, departing from Downtown Vancouver [3]. Since the N35 is a NightBus that operates from 2:00am until 5:00am, we will not be considering the route in our project. The busses on the 145, 143, 144 and R5 routes have a maximum capacity of 170, 120, 77 and 120 passengers respectively [4].

3.3 Ridership

To account for peak hours, we will be using the data in Figure 2 in our constraints. These forecasts were determined using a model created for the 2011 Burnaby Mountain Gondola Transit

Business Case Report. This model assumed gondola cars would have a capacity of 35 passengers. Additionally, we will be focusing on the gondola in the long-term, using the 2041 forecasted data.

Exhibit 2-10 – Ridership Forecasts with Evergreen Line

			BAU (Without Gondola)				With Gondola			
Year	Route	Service	Peak Headway (min)	AM Peak Hour Boardings	Estimated Daily Boardings	Peak Volume (pphpd)	Peak Headway (min)	AM Peak Hour Boardings	Estimated Daily Boardings	Peak Volume (pphpd)
2021	135	SFU – Downtown	4.0	2,081	24,200	946	4.0	1,420	16,500	421
	144	Metrotown Stn – SFU	10.5	1,119	13,000	293	10.5	1,079	12,600	293
	145EG	Production Stn – SFU – Burquitlam Stn	3.0	2,045	23,800	1,049	3.0	78	900	48
	BMGT	Burnaby Mtn Gondola	n/a	n/a	n/a	n/a	0.6	3,255	37,900	2,844
2041	135	SFU – Downtown	3.0	2,379	27,700	988	3.0	2,124	24,700	558
	144	Metrotown Stn – SFU	8.0	1,620	18,900	492	8.0	1,598	18,600	492
	145EG	Production Stn – SFU – Burquitlam Stn	2.5	2,657	31,000	1,282	2.5	107	1,200	60
	BMGT	Burnaby Mtn Gondola	n/a	n/a	n/a	n/a	0.6	4,174	48,600	3,341

pphpd: passengers per hour per direction

Figure 2: Ridership Forecasts

4 Assumptions

4.1 Operation Times

"Suppliers were asked to estimate costs associated with operating the BMGT from 6:00 AM to 1:00 AM the next day, 7 days per week – consistent with operating hours for TransLink's overall rapid transit network" [5]. Thus, we will assume that both the gondola and the busses will be in operation for 19 hours per weekday.

4.2 Peak and Non-Peak Hours

According to the 2009 Initial Feasibility Study, "[145 is] serviced with 10 buses leaving at frequent intervals during peak hours." Based on this statement, the peak hours for the 145 bus route are at 7:00am, 8:00am, 9:00am and 10:00am, when the bus departures occur at least 10 times per hour [3]. Because the study does not mention peak hours for the other bus routes, we will assume that each bus and gondola route will have the same peak hours as the 145 route. Thus there are a total of 4 peak hours and 15 non-peak hours during each weekday. Additionally, we will assume that the passenger demand is constant for both peak and non-peak hours.

4.3 Operation & Maintenance (O& M) Costs per Gondola Trip

In order to create our objective function, we need an approximate O&M cost of each gondola and bus trip from their station to the SFU Transit Exchange. Operating and maintaining the gondola will cost $54.2 million (discounted to present value) over a 25 year period [1]. We used this to find the O&M cost per trip, by dividing 54.2 million by the number of years (25), by the number of days in a year (365), by the number of hours in operation (19), and then by the largest possible number of gondola trips per hour (120). As a result, the cost per gondola trip was approximately $2.605. However, according to the 2018 feasibility study, a "*kinked* alignment would prove to be longer, slower [...] and more expensive to build." Operations costs for a "kinked" alignment would cost $5.3 million to operate per year compared to $4.1 million for a straight alignment. Using this ratio, we assumed that the O&M costs for routes A and C are $3.368 per gondola trip to the SFU Transit Exchange.

4.4 Operation & Maintenance (O&M) Costs per Bus Trip

According to an undisclosed Coast Mountain Bus Company supervisor, a bus costs approximately $1.7 per kilometre to operate and maintain, which includes the cost of fuel and labour. Using each bus trip distance, the O&M costs for the R5, 144, 145 and 143 routes are $30.6, $28.9, $13.43 and $11.73 per bus trip respectively.

To help confirm our assumptions, we used data from the 2018 Feasibility Study, which states that the gondola would cause a reduction of $ 89.3 million in bus O&M costs over a 25 year period. Using the data from Figure 2, we found that the number of total bus passengers would decrease from 38,800 to 22,250 per direction. Using a ratio of 16,550 (the reduction of passengers) to 38,800, we assume that the total bus O&M costs before the reduction is $209.356 million over a 25 year period. Thus, by dividing 209.356 million by the number of years (25), by the number of days in a year (365), by the number of hours in operation (19), the number of bus routes (4), and then by the largest possible number of bus trips per hour (20), we estimate O&M costs to be an average of $15.094 per bus trip to the SFU Transit Exchange, which helps confirm our assumption.

5 Decision Variables

We introduce a total of 16 decision variables. For each gondola and bus route shown in Figure 1, we will introduce two variables that represent the number of gondolas or buses that depart within a peak hour and non-peak hour.

G_{jp} = number of gondolas that run at route j during a peak hour,
where $j \in$ (A, B, C, D) and G_{jp} are integer

B_{ip} = number of buses that run at route i during a peak hour,
where $i \in$ (E, F, G, H) and B_{jp} are integer

G_{jn} = number of gondolas that run at route j during a non-peak hour,
where $j \in$ (A, B, C, D) and G_{jn} are integer

B_{in} = number of buses that run at route i during a non-peak hour,
where $i \in$ (E, F, G, H) and B_{jn} are integer

For example, B_{Gp} corresponds to the number of buses that leave from Production–Way University during a peak hour.

6 Constraints

In order to satisfy passenger demand, we want to make sure that the maximum bus and gondola capacity exceeds passenger demand for both peak hours and non-peak hours. We used Figure 2 to determine passenger demand, and gondola and bus capacities as our coefficients.

Total Passenger Demand:

Peak Hours: $120B_{Ep} + 77B_{Fp} + 120B_{Gp} + 120B_{Hp} + 35G_{Ap} + 35G_{Bp} + 35G_{Cp} + 35G_{Dp} \geq 4451^{*}$

* 4451 = 558 (135 peak volume) + 492 (144 peak volume) + 60 (145EG peak volume) + 3,341 (BMGT peak volume)

Non-Peak Hours: $120B_{En} + 77B_{Fn} + 120B_{Gn} + 120B_{Hn} + 35G_{An} + 35G_{Bn} + 35G_{Cn} + 35G_{Dn} \geq 1915^{*}$

* 1915 = ((24,700 + 18,000 + 48,600 + 1,200)/2 – 4(4451)) / 15

This calculation was made by the sum of estimated daily boarding for each service, divided in half to obtain the number of passengers for a single direction. Then we subtracted it by the number of peak hour passengers per hour (4451) multiplied by the number of peak hours in a day (4). Finally, we divide by the number of non-peak hours in a day (15).

Peak Hour Constraints per Route:

R5: $120B_{Ep} \geq 558$

144: $77B_{Fp} \geq 492$

145, 143 & Gondolas: $120(B_{Gp} + B_{Hp}) + 35(G_{Ap} + G_{Bp} + G_{Cp} + G_{Dp}) \geq 60 + 3{,}341$

Non-Peak Hour Constraints per Route:

R5: $120B_{En} \geq (24{,}700/2 – (4 * 558)) / 16^{*}$

* We divide by the number of hours that the R5 bus route is in operation, 16 instead of 15 (Moovit, 2020).

144: $77B_{Fn} \geq (18{,}000/2 – (4 * 492)) / 15$

145 & 143 & Gondolas: $120(B_{Gp} + B_{Hp}) + 35(G_{Ap} + G_{Bp} + G_{Cp} + G_{Dp}) \geq 753.067^{*}$

* 753.067 = ((48,600 +1,200)/2 – 4(3,341 + 60)) / 15

In our initial iterations of the model, we were getting results that were unreasonably high. Thus, we constrained the gondola trips to a maximum of 120 trips per direction per hour (one gondola every 30 seconds) and the bus trips to a maximum of 60 trips per direction per hour (one bus every minute).

Gondola/Bus Restrictions Per Hour:

$$G_{jk} \leq 120 \text{ where } j \in \text{(A, B, C, D) and k} \in \text{(p, n)}$$

$$B_{ik} \leq 60 \text{ where } i \in \text{(E, F, G, H) and k} \in \text{(p, n)}$$

7 Objective Function

Our objective is to reduce the per hour O&M costs for a combination of gondola and bus routes during peak and non-peak hours. Using our estimated O&M costs, we created the following objective function. We did not factor in capital costs for running the gondola, in order to accurately compare gondola costs against bus costs.

Min $Z = 3.368(G_{Ap} + G_{An} + G_{Cp} + G_{Cn}) + 2.605(G_{Bp} + G_{Bn} + G_{Dp} + G_{Dn}) + 30.6(B_{Ep} + B_{En}) + 28.9(B_{Fp} + B_{Fn}) + 13.43(B_{Gp} + B_{Gn}) + 11.73(B_{Hp} + B_{Hn})$

8 Results

We found the following solution in R:

Z = $1,053.8 per two hours of operation and maintenance: one peak hour and one non-peak hour

G_{Ap} = 0 gondolas per peak hour at route A	B_{Ep} = 5 busses per peak hour at route E
G_{An} = 98 gondolas per non-peak hour at route A	B_{En} = 7 busses per non-peak hour at route E
G_{Bp} = 0 gondolas per peak hour at route B	B_{Fp} = 0 busses per peak hour at route F
G_{Bn} = 0 gondolas per non-peak hour at route B	B_{Fn} = 0 busses per non-peak hour at route F
G_{Cp} = 0 gondolas per peak hour at route C	B_{Gp} = 6 busses per peak hour at route G
G_{Cn} = 22 gondolas per non-peak hour at route C	B_{Gn} = 7 busses per non-peak hour at route G
G_{Dp} = 0 gondolas per peak hour at route D	B_{Hp} = 0 busses per peak hour at route H
G_{Dn} = 0 gondolas per non-peak hour at route D	B_{Hn} = 0 busses per non-peak hour at route H

The most cost efficient solution would be to run gondola route B without bus routes F (145) and H (143), which can completely satisfy passenger demand for both peak and non-peak hours. This would bring O&M costs to $1,053.8 for two hours: one peak hour and one non-peak hour. Specifically, O&M costs would be $610.59 per peak hour.

In order to satisfy passenger demand during peak hours, 98 gondolas need to run from Production–Way University Station to SFU, which results in one gondola every 36.7 seconds. This is not far from the proposed gondola frequency of 30 seconds in the 2011 Business Case. In order to satisfy passenger demand during non-peak hours, only 22 gondolas need to run Production–Way University Station to SFU. However, the gondolas will most likely by running at a constant speed throughout all operation times, to prevent reducing the commute time to the mountain. Thus, even during non-peak hours, 98 gondolas will run to the SFU Transit Exchange per hour. This brings our estimated costs to $1,251.78 for two hours.

Another solution is to also run gondola route D without bus routes F and H. Since our calculated cost per gondola trip is the same for gondola route B and D, our model shows no difference in these solutions. In reality, this is not the case. Gondola route D has poor integration with Burquitlam Station, which would most likely increase costs for that route [2].

The solutions for R5 and 144 busses from Burrard and Metrotown Station are trivial, and were not needed in our model. Because we used forecasted passenger demand with the gondola already implemented, these two decision variables were not dependent on any of the other decision variables in their constraints. Additionally, the solution states that the non-peak hour bus frequency for both the R5 and 144 routes are greater than the *peak* hour bus frequency, which obviously does not make sense. This is a result of the data from Figure 2; the peak volumes for the R5 and 144 routes are both less than the calculated boardings per non-peak hour. This shows that the forecasts from Figure 2 could be questionable.

9 Limitations and Improvement

Although it is more cost efficient to remove the 143 bus route, this may be inconvenient for students who live around Burquitlam Station. We should have also factored in the total commute time in our objective. However, it takes approximately six minutes to reach Production–Way University Station from Burquitlam Station by Skytrain, and a six minute gondola trip to the SFU, a total of 12 minutes, which is approximately equal to the 143 bus route commute time of 13 minutes.

If the city of Burnaby had only intended to reduce costs, a gondola would have been built by now. However, residents' privacy concerns have posed a major challenge to the Gondola Transit Project. Because we did not create an objective to minimize residential property crossings, gondola route B may not be the most cost efficient solution.

Initially, as we were creating the problem, it was unclear that the solution would have turned out to be simple. A multi-objective model would have made for a slightly more interesting problem. With more time, we would have liked to minimize kilometres of residential crossings and passenger travel time, in addition to cost.

References

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[3] Moovit. Line route 145 - translink - bus schedules. https://moovitapp.com/greater_vancouver_bc-145/lines/145/707332/3012233/en?customerId=4908&ref=2poiType=line, 2020.

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