Optimizing Financial Resource Allocation to Maximize the University of British Columbia's Student Satisfaction Index

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Introduction

The significance of prioritizing student well-being within the University of British Columbia (UBC) holds immense importance. Studies indicate that educational institutions fostering holistic approaches to encourage student development and learning while ensuring their well-being experience a notable improvement in academic performance [6]. A nurturing and encouraging campus atmosphere boosts students' potential for academic achievement, fosters meaningful learning engagements, and cultivates enduring relationships with both peers and faculty. Students commonly encounter various challenges and pressures, spanning academic rigor, social dynamics, and personal or financial constraints. Given Vancouver's escalating cost of living, coupled with the financial strain on many students and families, it is crucial for the university to conscientiously consider student fees and their allocation, ensuring they continue to effectively benefit the student community.

A primary concern revolves around the lack of action taken based on the survey outcomes conducted by UBC. Policy LR4 [5], known as the Consultation with Students about Tuition and Mandatory Fees Policy, outlines a procedure for engaging with the Elected Student Leadership and students. This process involves administering a survey via email to the student body for voluntary participation. Despite the clear and overwhelming opposition shown in the annual survey results toward any tuition fee hikes, these proposed increases persist each year.

The survey results [1] [2] [3] [4] also shed light on priority areas identified by students, such as financial support, academic excellence, and student health and well-being. These essential services contribute significantly to student learning but require financial resources, often sourced from tuition fees as well as other areas. For instance, eliminating student fees entirely could enhance student satisfaction, yet it would deprive essential student services of funding. Conversely, significantly high tuition fees may adversely impact student satisfaction, although they could ensure optimal operation of all student services and potentially more.

To address this issue, we propose using linear optimization. This method aims to maximize the satisfaction and well-being of domestic undergraduate students through the funding for student services and infrastructure based on current tuition fees.

Methodology

Linear Programming

Linear programming is a mathematical method used for optimizing a linear objective function, subject to a set of linear constraints. The goal is to determine the values of decision variables that optimize the objective function while satisfying all the given constraints.

The general form of a linear programming problem is

$$\begin{cases} \text{maximize} & cx \\ \text{subject to} & Ax \leq b \\ & 0 \leq x \end{cases}$$

where x is the decision variables vector, c is a coefficient vector for the objective function, A is a coefficient matrix for the constraints, and b is the constraints vector.

We will apply linear programming in order to determine an optimal allocation of tuition in order to maximize the overall Student Satisfaction Index (SSI).

Data

To begin our investigation, our initial step involved gathering all necessary data. This primarily included information on tuition expenses, the allocation and utilization of tuition-generated revenue by the university, as well as the sentiments and viewpoints of the student body.

Initially, we used LR4 for the years 2020 to 2023, presented to the UBC Board of Governors. Our project heavily relies on the data from these reports. These documents are structured based on annual surveys distributed among the student population. These surveys are used to get a better understanding of the student body in areas such as levels and sources of financial stress, student opinions on the proposed tuition hikes, and prioritization of university areas, including financial aid, learning accessibility, climate change, among others. The survey data predominantly tracks these topics using Likert scales and ranking systems. There are optional text boxes provided, allowing respondents to offer written feedback and commentary.

Given our focus on addressing the tradeoff between funding for student services and student satisfaction using linear programming, it's important that our objective functions and constraints are linear. Consequently, our collected data necessitates linear regression analyses to establish linear relationships. These assumptions include assuming linear relationships between certain variables, among other things that we will detail later.

We have used LR4 data from the last three years, along with the projected current year, to establish the link between annual proposed domestic undergraduate tuition and the average associated satisfaction level. Surveys outlined incoming tuition fee increments (typically 2% for undergraduate domestic students) and elicited respondents' agreement levels via ranking or the Likert scale, encompassing a scale from strongly disagree to strongly agree. Each Likert scale rating was converted to a numerical value from one to seven, denoting varying degrees of agreement, and then translated into an approximate percentage value. It is important to note that not all surveys included a 'neutral' response (assigned a value of 3). We visualized this thorough linear regression analysis, which led to the an explicit formula depicting the relationship between tuition changes and student satisfaction (see Figure 1).

The visual representation revealed a clear negative correlation between increased tuition and student satisfaction, particularly evident in the last four surveys where the average satisfaction reached at most 27% on the Likert scale (approximately 1.90, denoting disagreement or strong disagreement with the proposed tuition hike). Considering the evident strong opposition to tuition increases, our approach for analyzing student service funding assumes a fixed tuition based on the current cost. Moreover, it factors in fluctuations in the size of the student body, reflecting the prevailing sentiment against any rise in tuition fees.

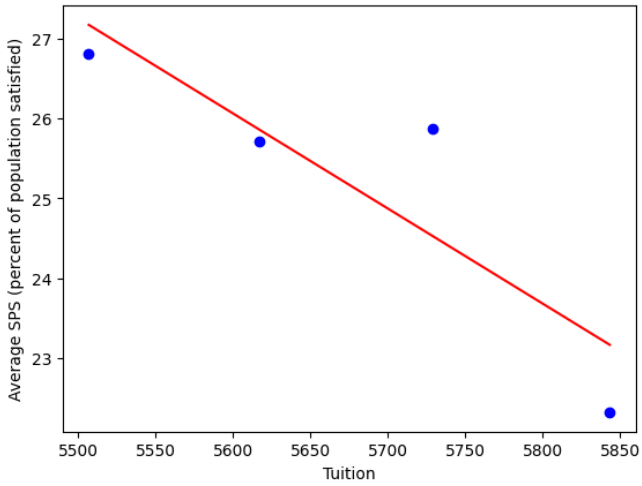


Figure 1: Proposed tuition and average student population satisfaction

Upon formulating our dataset and framing the linear programming problem, our goal is to use the OR-Tools package in Python to compute the numerical solutions. This package will help in solving the linear programming model and deriving the numerical values that solve the optimization problem we have constructed, as well as compute sensitivity data.

The Primal: Maximizing Satisfaction

We have selected the overall Student Satisfaction Index (SSI) as the variable to be maximized in our primal problem, which we define to be the weighted sum of multiple SSI factors that pertain to the funding of certain services, while ensuring that students at UBC experience the highest level of utility throughout their tenure. The constraints in this optimization problem are the minimum/maximum budgets allocated from tuition and the minimum acceptable SSI for certain services. In this scenario we will be focusing only on domestic undergraduate students, which make up the majority of the student body, and excluding medical, law and other post-undergraduate studies in order to keep the data that we use consistent.

Decision Variables

The categories that we have chosen are those eligible to be voted on in the Consultation with Students about Tuition and Mandatory Fees survey over the past few years. This is summarized in Table 1.

Category
Financial Support
Student Health & Wellbeing
Academic Excellence
Accessible Learning
Climate Change
Equity, Diversity, & Inclusion Initiatives
Formal & Informal Spaces on Campus

Table 1: Categories corresponding to decision variables for the linear programming problem

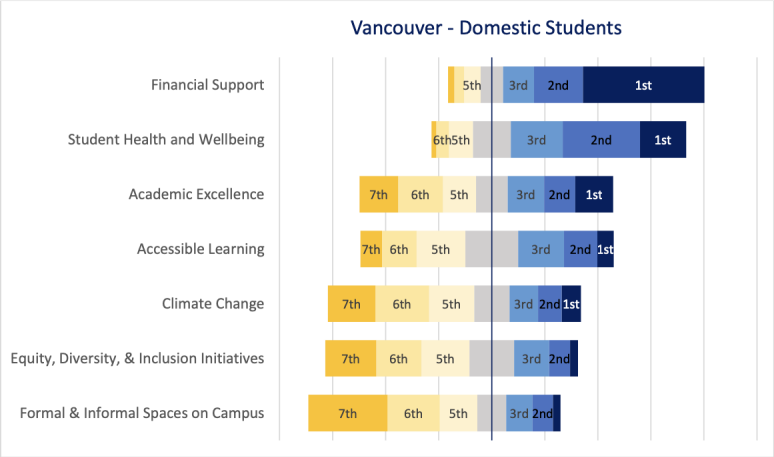
The variables x_i are the percentage of domestic undergraduate students that are satisfied with each respective category. Hence, they are bounded between 0 and 100, with 0 being 0% of the student population

is satisfied with that category, compared to 100 being 100% of the student population is satisfied with that underlying category.

Objective Function

Our objective function will be the weighted sum of the satisfaction for each service funded. To determine the weight coefficients (c_i's) of each category, we have used LR4. The most recent survey showed results on students' preferences to which category they believe required the most attention. The greater the weight, the larger the impact on the overall SSI. By taking the student responses and and standardizing them, we can then ensure that each category accurately reflects the survey results, while also ensuring that the total sum of the SSI does not exceed 100.

Figure 2 shows the data we are using to determine the weights c_i based on the 2023/2024 survey results [4].



Ranked Priority	1st	2nd	3rd	4th	5th	6th	7th	Total
Financial Support	47%	19%	12%	9%	6%	4%	2%	2416
Student Health and Wellbeing	18%	30%	20%	15%	9%	5%	2%	2401
Academic Excellence	15%	12%	14%	12%	13%	18%	15%	2390
Accessible Learning	6%	13%	18%	21%	19%	14%	9%	2387
Climate Change	8%	9%	11%	14%	18%	21%	19%	2384
Equity, Diversity, & Inclusion Initiatives	3%	8%	14%	18%	19%	18%	20%	2381
Formal & Informal Spaces on Campus	3%	8%	10%	11%	15%	21%	31%	2375

Figure 2: Domestic UBC student preferences of financial allocation

To calculate this we multiplied the percentage of students that ranked each category in first place by seven, the percentage of students who ranked each category in second by six, and so on to get a total value per category. We then standardized the satisfaction category values such that a maximum value of 100 will indicate that everyone is satisfied with all of the categories. Note that $\sum_{i=1}^{7} c_i = 1$. The results are summarized in Table 2.

Category	Coefficient (c_i)
Financial Support	0.204
Student Health & Wellbeing	0.181
Academic Excellence	0.138
Accessible Learning	0.139
Climate Change	0.121
Equity, Diversity, & Inclusion Initiatives	0.116
Formal & Informal Spaces on Campus	0.101
Total	**1.000**

Table 2: Coefficient matrix for the objective function

Constraints

The first constraint is that we cannot have the allocated funding for services from tuition exceed the total tuition amount.

For the general case presented we can find the total domestic undergraduate tuition revenue from previous UBC financial statements [7] [8]. Even though there are no exact numbers, we have extrapolated the data by multiplying the student enrolment statistics [8] from each faculty by their respective domestic undergraduate tuition [7]. We have included this data in Table 3.

Faculty	Student Population	Tuition	Total tuition
Applied Science	4,230	$7,693.04	$32,543,082.00
Arts	10,123	$5,843.40	$59,152,738.20
Forestry	726	$5,843.40	$4,242,308.40
Commerce	3,842	$8,658.90	$33,267,493.80
Land and Food Systems	1,326	$6,232.96	$8,264,904.96
Science	7,511	$5,843.40	$43,889,777.40
Kinesiology	1,256	$5,843.40	$7,339,310.40
International Economics	192	$9,349.50	$1,795,104.00
Music	191	$6,622.52	$1,264,901.32
Total	**29,397**	**-**	**$191,759,620.50**

Table 3: Undergraduate tuition fees per faculty

The coefficients for this constraint correspond to the dollar-value of the increase of each corresponding category by 1. That means if we wish for an additional 1% of the student population to be satisfied with a certain category, we must invest a_i dollars into the category. Each category should have varying coefficients, as an extra dollar might have more impact on one category than another.

To determine this, we used surveys [9] [17] [18] [19] [20] which asked UBC students to vote on whether they were satisfied on the attention that UBC was providing to certain categories. Some surveys did not directly match the categories we are interested in, so we extrapolated some information. For example, a survey question in asked "How concerned are you about being able to afford Medical, dental, and mental health financial obligations over the current academic term" [18] which we then interpreted the results to match our category "Student Health and Wellbeing" satisfaction.

Some survey results were presented as a percentage of students that voted that they were satisfied with a certain category. Those results we used directly. Other survey results were presented using a Likert scale. In that case we standardised the results so that they would be presented as a percent of satisfaction to match our data.

The satisfaction results over the past three years are summarized in Table 4, with each entry being the satisfaction for that category for that year.

Category	2020	2021	2022
Financial Support	41	43	42
Student Health and Wellbeing	35	35	34
Academic Excellence	72	69	56
Accessible Learning	50	53	48
Climate Change	42	45	54
Equity, Diversity, & Inclusion Initiatives	48	49	59
Formal & Informal Spaces on Campus	60	50	56
Average	**51.1**	**50.6**	**51.3**

Table 4: Student satisfaction from surveys 2020-2022

Using financial statements [10] [11] [12] [13] [14] [15] [16] and budget documents [21] [22], we found the total amount of money that UBC has invested into each of these categories. Similarly to the survey results, we had to make some assumptions about the data given to us. We had to use averages of various reports available to determine the budget that UBC allocated to Student Health and Wellbeing, as there are many different parts to UBC's commitment to that category. Those values might have to be looked at as placeholders, due to the ambiguity.

The financial results over the past three years are summarized in Table 5.

Category	2020	2021	2022
Financial Support	$392,300,000.00	$392,800,000.00	$394,300,000.00
Student Health and Wellbeing	$450,000,000.00	$510,000,000.00	$550,000,000.00
Academic Excellence	$104,700,000.00	$104,200,000.00	$103,600,000.00
Accessible Learning	$51,300,000.00	$55,200,000.00	$54,900,000.00
Climate Change	$1,294,800.00	$1,312,971.00	$1,092,175.00
Equity, Diversity, & Inclusion Initiatives	$8,006,000.00	$8,226,000.00	$10,226,000.00
Formal & Informal Spaces on Campus	$245,870,000.00	$248,080,000.00	$269,780,000.00
Total	**$1,253,470,800.00**	**$1,319,818,971.00**	**$1,383,898,175.00**

Table 5: UBC total investment 2020-2022

To account for inflation [23] and to take into consideration the changing student population, we have adjusted the budget so that it accurately reflects the current value of the Canadian dollar and student population. The inflation and student population-adjusted financial results over the past three years are summarized in Table 6.

Finally, we are able to take the year-over-year (YoY) change in the adjusted investment and divide it by the YoY change in student satisfaction to find a cost for an increase of 1 in satisfaction for a category. We then take the average of the two changes to determine our a_{1j} coefficients, where j is the number of variables in our linear programming problem (five). The difference and cost for increase of satisfaction results are summarized in Table 7.

We notice that there are two categories that have negative costs associated with them; Student Health and Wellbeing and Climate Change. Intuitively, this would suggest that decreasing the budget associated to these categories would increase the student satisfaction. This is obviously not the case, since any increase in funding on one category should increase student satisfaction when considered independently. Additionally, we do not have financial information for the Student Health and Wellbeing category in

Category	2020	2021	2022
Financial Support	$422,239,112.98	$405,865,853.28	$394,300,000.00
Student Health and Wellbeing	$484,342,597.10	$526,964,320.71	$550,000,000.00
Academic Excellence	$112,690,377.59	$107,666,043.56	$103,600,000.00
Accessible Learning	$55,215,056.07	$57,036,138.24	$54,900,000.00
Climate Change	$1,393,615.10	$1,356,644.85	$1,092,175.00
Equity, Diversity, & Inclusion Initiatives	$8,616,992.96	$8,499,624.51	$10,226,000.00
Formal & Informal Spaces on Campus	$264,634,031.89	$256,331,977.81	$269,780,000.00
Total	**$1,349,131,783.69**	**$1,363,720,602.96**	**$1,383,898,175.00**

Table 6: UBC adjusted investment 2020-2022

Category	2020-2021 Change	2021-2022 Change	Average (a_{1j})
Financial Support	$(8,186,629.85)	$11,565,853.28	$1,689,611.72
Student Health and Wellbeing	$0	$(23,035,679.29)	$(11,517,839.65)
Academic Excellence	$1,674,778.01	$312,772.58	$993,775.30
Accessible Learning	$607,027.39	$427,227.65	$517,127.52
Climate Change	$(12,323.42)	$(29,385.54)	$(20,854.48)
Equity, Diversity, & Inclusion Initiatives	$(117,368.45)	$172,637.55	$27,634.55
Formal & Informal Spaces on Campus	$830,205.41	$2,241,337.03	$1,535,771.22

Table 7: Cost of increase by category 2020-2022

2020-2021, so we were unable to find an accurate change in funding. Since these categories will skew our SSI upwards, we will entirely omit these categories, and proceed by only using the remaining five variables.

Thus, we must revisit our objective function. From removing two of the categories from our analysis and re-calibrating their values to ensure they sum to 1, we now have the coefficients for the objective function summarized in Table 8.

Category	Decision Variable (x_i)	Coefficient (c_i)
Financial Support	x_1	0.292
Academic Excellence	x_2	0.198
Accessible Learning	x_3	0.199
Equity, Diversity, & Inclusion Initiatives	x_4	0.166
Formal & Informal Spaces on Campus	x_5	0.145
Total	-	**1.000**

Table 8: Decision variable assignments and final objective function coefficients.

We also want to make sure that each category has a minimum satisfaction of 20% — in equation form, we must have $x_1, x_2, x_3, x_4, x_5 \geq 20$. In order to maintain UBC's EDI commitments, we have included a minimum tuition allocation of $2.5 million towards the Equity, Diversity, & Inclusion initiatives category, so $27,634.55x_4 \geq 2,500,000$.

Lastly, we have introduced a maximum combined spending on Accessible Learning and Academic Excellence of $145 million. We recognize that these categories are related and symbiotic in nature, so we feel that it is logical to cap their combined expenditure to limit 75% of the allocation to at most two categories.

To summarize, our constraints will be

- Total tuition such that the contribution to all the categories is less than or equal to the total tuition.
- Maximum satisfaction per category of 100.
- Minimum satisfaction per category of 20.
- Minimum spending on Equity, Diversity, & Inclusion Initiatives of $2.5 million.
- Maximum combined spending on Accessible Learning and Academic Excellence of $145 million.

The constraints we have selected suggest the possibility of an infeasible region within our initial primal solution. Specifically, the insistence on maintaining a minimum satisfaction level could lead to an infeasible solution. Therefore, we have carefully structured our minimum satisfaction constraint to avoid encountering an infeasible region, making sure that for the given tuition, we will not have a problem that is unsolvable.

We would use the auxiliary method to address an infeasible dictionary by introducing an artificial variable to create a modified problem. By minimizing this variable in the auxiliary objective function, the method aims to attain feasibility. Solving this auxiliary problem helps determine if the original problem becomes feasible. Removing artificial variables and re-solving leads the problem towards a feasible solution. This method gives a iterative transformation of an infeasible initial solution into a feasible one, making sure the application of standard linear programming methods to find an optimal solution.

Final Problem

Hence, we want to investigate a linear programming problem which has the general form of:

$$(P) = \begin{cases} \text{maximize} & 0.292x_1 + 0.198x_2 + 0.199x_3 + 0.166x_4 + 0.145x_5 \\ \text{subject to} & 1,689,611.72x_1 + 993,775.30x_2 + 517,127.52x_3 + 27,634.55x_4 \\ & \qquad +1,535,771.22x_5 \leq 191,759,620.50 \\ & 27,634.55x_4 \geq 2,500,000.00 \\ & 993,775.30x_2 + 517,127.52x_3 \leq 145,000,000.00 \\ & 20 \leq x_1, x_2, x_3, x_4, x_5 \leq 100 \end{cases}$$

where x_1 is Financial Support, x_2 is Academic Excellence, x_3 is Accessible Learning, x_4 is Equity, Diversity, & Inclusion Initiatives, and x_5 is Formal & Informal Spaces on Campus.

In standard form, we have:

$$(P) = \begin{cases} \text{maximize} & 0.292x_1 + 0.198x_2 + 0.199x_3 + 0.166x_4 + 0.145x_5 \\ \text{subject to} & 1,689,611.72x_1 + 993,775.30x_2 + 517,127.52x_3 + 27,634.55x_4 \\ & \qquad +1,535,771.22x_5 \leq 191,759,620.50 \\ & -27,634.55x_4 \leq -2,500,000.00 \\ & 993,775.30x_2 + 517,127.52x_3 \leq 145,000,000.00 \\ & -x_1 \leq -20 \\ & -x_2 \leq -20 \\ & -x_3 \leq -20 \\ & -x_4 \leq -20 \\ & -x_5 \leq -20 \\ & x_1 \leq 100 \\ & x_2 \leq 100 \\ & x_3 \leq 100 \\ & x_4 \leq 100 \\ & x_5 \leq 100 \\ & x_1, x_2, x_3, x_4, x_5 \geq 0 \end{cases}$$

Solution

Using the OR-Tools package in Python, we are able to get an optimal solution of $(x_1, x_2, x_3, x_4, x_5) = (20.0, 73.2, 100.0, 100.0, 20.0)$, with an optimal value of 59.7. This solution marks an 8.4 increase in overall SSI compared to the 2022 results, which previously represented the highest average SSI from Table 4. This signifies a notable enhancement in overall SSI. To better understand what this solution means, we have compared this solution against the prior SSI and investments in each category derived from LR4 and UBC's approximate expenditures per category, proportionally scaled to the size of the constant tuition pool employed in this analysis.

Category	Previous Satisfaction	Optimal Satisfaction	Change in Satisfaction
Financial Support	42	20.0	- 22
Academic Excellence	56	73.2	+ 17.2
Accessible Learning	48	100.0	+ 52
Equity, Diversity, & Inclusion Initiatives	59	100.0	+ 41
Formal & Informal Spaces on Campus	56	20.0	- 36

Table 9: Satisfaction change comparison

Category	Previous Investment	Optimal Investment	Change In Investment
Financial Support	$90,790,434.22	$33,792,234.40	- $56,998,199.82
Academic Excellence	$23,854,651.24	$72,775,754.93	+ $48,921,103.69
Accessible Learning	$12,641,123.10	$51,712,752.00	+ $39,071,628.90
Equity, Diversity, & Inclusion Initiatives	$2,254,610.65	$2,763,455.00	+ $508,844.35
Formal & Informal Spaces on Campus	$62,118,801.28	$30,715,424.40	- $31,403,376.88

Table 10: Change in investment allocation

We can see that there are fairly drastic changes in our optimal satisfaction levels compared to the previous satisfaction levels from LR4. The categories Academic Excellence, Accessible Learning, and Equity,

Diversion, & Inclusion Initiatives have a large increase in satisfaction each. This is because those three categories have the smallest amount of funding needed to increase the satisfaction for each category respectively. Financial Support and Formal & Informal Spaces on Campus each have high costs associated with an increase of 1 in satisfaction, so it is logical that our solution has a decrease in the funding allocated for them.

We are able to leverage sensitivity analysis in OR-Tools to get information about the "shadow prices" and slack in each constraint as in Table 11. The shadow price for a given constraint is the change in the optimal solution value for an increase of one unit of the value on the constraint's right-hand side. The slack for a given constraint is the amount of resource that is unused — any change in a constraint with a slack value of 0 will result in a change of the objective function value, as can be seen by the fact that every non-zero shadow price has a corresponding slack value of 0. Each slack value is a range of feasibility for that constraint, where changing it within that range would not change the optimal solution value [25].

Constraint	**Shadow Price**	**Slack**
1	$1.989 \cdot 10^{-7}$	0
2	0	$2.635 \cdot 10^{5}$
3	0	$2.051 \cdot 10^{7}$
4	$4.438 \cdot 10^{-2}$	0
5	0	$5.323 \cdot 10^{1}$
6	0	80.00
7	0	80.00
8	$1.609 \cdot 10^{-1}$	0
9	0	80.00
10	0	$2.677 \cdot 10^{1}$
11	$9.597 \cdot 10^{-2}$	0
12	$1.605 \cdot 10^{-1}$	0
13	0	80.00

Table 11: Shadow prices and slack for the constraints in the primal problem.

The shadow price related to the first constraint shows that a reduction of $\$1$ in the aggregate tuition corresponds to a decrease of our optimal solution (SSI) by $1.989 \cdot 10^{-7}$. In other words, a decrease of 1 in the overall SSI is associated with a reduction of \$19,890,000 in total tuition. Changes to the second and third constraints—specifically, diminishing the minimum funding allocated for Equity, Diversity & Inclusion Initiatives or increasing the total maximum funding allocated for Accessible Learning and Academic Excellence—have no influence on the value of the objective solution. The fourth and eighth constraints have shadow prices of $4.438 \cdot 10^{-2}$ and $1.609 \cdot 10^{-1}$ respectively. These values indicate that a decrease by 1 in the minimum satisfaction level for Financial Support and Formal & Informal Spaces on Campus would result in marginal increases in the objective function value.

The fifth, sixth, and seventh shadow prices highlight that funding allocations to Academic Excellence, Accessible Learning, and Equity, Diversity & Inclusion Initiatives remain unaffected by the minimum satisfaction value of 20 set for each category. This observation aligns with their optimal satisfaction values exceeding the minimum 20 threshold. Additionally, shadow prices of 0 for the ninth, tenth, and thirteenth constraints imply that reducing the maximum satisfaction value from 100 by 1 to 99 for Financial Support, Academic Excellence, and Formal & Informal Spaces on Campus would not alter the objective solution value. This correlation is sensible given that these categories are not funded to

achieve a 100% satisfaction. However, the eleventh and twelfth non-zero shadow prices indicate that Accessible Learning and Equity, Diversity, & Inclusion Initiatives would cause marginal decreases in the optimal solution value if the maximum individual satisfaction was reduced from 100 by 1 to 99 for those categories. This rationale aligns with these being the only two categories set at 100 satisfaction with maximal funding in our optimal solution.

The Dual: Minimizing Tuition Allocation

Let us now consider the dual problem. Here is the dual problem in standard form:

$$(D) = \begin{cases} \text{minimize} & 191,759,620.50y_1 - 2,500,000y_2 + 145,000,000y_3 - 20y_4 - 20y_5 - 20y_6 \\ & \qquad -20y_7 - 20y_8 + 100y_9 + 100y_{10} + 100y_{11} + 100y_{12} + 100y_{13} \\ \text{subject to} & -1,689,611.72y_1 + y_4 - y_9 \leq 0.292 \\ & -993,775.30y_1 - 993,775.30y_3 + y_5 - y_{10} \leq 0.198 \\ & -517,127.52y_1 - 517,127.52y_3 + y_6 - y_{11} \leq 0.199 \\ & -27,634.55y_1 + 27,634.55y_2 + y_7 - y_{12} \leq 0.166 \\ & -1,535,771.22y_1 + y_8 - y_{13} \leq 0.145 \\ & y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9, y_{10}, y_{11}, y_{12}, y_{13} \geq 0 \end{cases}$$

Using the OR-Tools package in Python, we are able to get an optimal dual value of 59.75, which matches our primal value. This satisfies the Strong Duality Theorem, and implies a correct procedure was followed for the computation for the dual problem. The optimal dual solution is summarized in Table 12.

Variable	Value
y_1^*	$1.989 \cdot 10^{-7}$
y_2^*	0.000
y_3^*	0.000
y_4^*	0.044
y_5^*	0.000
y_6^*	0.000
y_7^*	0.000
y_8^*	0.161
y_9^*	0.000
y_{10}^*	0.000
y_{11}^*	0.096
y_{12}^*	0.161
y_{13}^*	0.000

Table 12: Dual optimal solution

When looking back at Table 11 and Table 12, we can see that the dual optimal solution exactly matches the shadow prices for the constraints of the primal problem. This directly ties to the Sensitivity Theorem, which determines how variations in constraint values and objective function coefficients impact the optimal solution and objective value. It examines shadow prices [24] for allowable ranges in constraint value perturbation. It provides information into the solution's sensitivity to parameter changes, helping understanding the solution's robustness. This is only applicable if the solutions are non-degenerate, which they are in our analysis.

Limitations

Our analysis encounters several limitations when it comes to maximizing SSI. We have been constrained by limited available data, necessitating the extrapolation of financial information. While we have diligently transcribed most values from documents, discrepancies might exist due to potential mismatches with the categories assigned. There is a possibility of resource double-counting, stemming from the utilization of diverse documents containing overlapping information.

Notably, the funding sources for the selected categories are not exclusively reliant on student tuition. We have also only used student tuition values for classes, which does not include the large amount of other membership, professional, improvement, and other fees that are essential for improving services. UBC also owns a substantial endowment fund and numerous partnerships with governments, corporations, and external investors. We also decided to drop two categories without adjusting the total tuition, which further could skew our values. Hence, our results should be interpreted in terms of proportional allocation rather than absolute value allocation.

Our analysis further constrained itself by utilizing only three years of data to determine most year-on-year changes. This approach significantly amplifies the variance in our results and may not yield the most accurate coefficients in our linear constraints. Employing data spanning a longer period would have provided more substantial insights into the total 'cost' associated with each category. It could have potentially eliminated the necessity to discard certain categories, offering a more realistic representation of the evolution of student satisfaction over time.

Conclusion

Through linear programming, we have been able to find a tuition allocation plan that redistributes $148,640,153.64 of the total $191,759,620.50 tuition, resulting in an 8.4 increase in overall SSI. Our analysis involved a comprehensive examination of the data employed and the derived solution, inclusive of a thorough sensitivity analysis. This approach not only optimized tuition allocation but also provided insights into the relationship between funding distribution and student satisfaction, offering valuable considerations for future policy decisions.

As students who pay tuition to UBC, we believe that using data and optimization tools can construct more equitable and satisfactory tuition and funding frameworks. Currently, there is limited transparency regarding the allocation of funds to the seven specified categories in the survey. Questions arise regarding the tangible impact of funding directed towards areas like Equity, Diversity & Inclusion Initiatives or Academic Excellence. Similarly, understanding the direct outcomes of increased funding for Accessible Learning or Formal & Informal Spaces on Campus is crucial. These are aspects that students should have access to and witness in their daily experiences at the university. While our analysis was constrained by assumptions and limited data access compared to the university's internal data, we perceive this investigation as a starting point for a more comprehensive and essential in-depth analysis that UBC should undertake.

References

[1] ANDREW SZERI, ET AL "Tuition Consultation Report for the 2020/2021 Proposed Tuition Increases", Presented to UBC Board of Governors, 2020.

[2] ANDREW SZERI, ET AL "Tuition Consultation Report for the 2021/2022 Proposed Tuition Increases", Presented to UBC Board of Governors, 2021.

[3] ANDREW SZERI, ET AL "Tuition Consultation Report for the 2022/2023 Proposed Tuition Increases", Presented to UBC Board of Governors, 2022.

[4] AINSLEY CARRY, ET AL "Tuition Engagement 2023-2024 and Student Affordability Task Force Update", Presented to UBC Board of Governors, 2023.

[5] UBC BOARD OF GOVERNORS "Tuition Consultation Policy (LR4)", Last updated 2019.

[6] VASANT NAMDEO BORKAR "Positive school climate and positive education: Impact on students well-being", Indian Journal of Health and Wellbeing, 2016, 7(8), 861-862.

[7] UBC STUDENT SERVICES "Undergraduate tuition fees", https://students.ubc.ca/enrolment/finances/tuition-fees/undergraduate-tuition-fees.

[8] UBC "UBC PAIR Program Enrolments"

[9] UBC PAIR "UBC PAIR Surveys of Current Students", https://pair.ubc.ca/surveys/surveys-current-students/.

[10] UBC BOARD OF GOVERNORS "UBC Consolidated Financial Statements as March 31, 2022 ", https://bog3.sites.olt.ubc.ca/files/2022/06/5.1_2022.06_UBC-Consolidated-Financial-Statements-as-at-March-31-2022.pdf.

[11] UBC BOARD OF GOVERNORS "STUDENT FINANCIAL SUPPORT ANNUAL REPORT 2020-2021", https://bog3.sites.olt.ubc.ca/files/2021/06/5_2021.06_Student-Financial-Support-Annual-Report-2020-2021.pdf.

[12] UBC FINANCE "UBC Financial Reports", https://finance.ubc.ca/reporting-planning-analysis/financial-reports.

[13] UBC SUSTAINABILITY "UBC Sustainability CLIMATE ACTION PLAN", https://sustain.ubc.ca/campus/climate-action/climate-action-plan.

[14] UBC SUSTAINABILITY "UBC Climate Change Accountability Report 2020", https://sustain.ubc.ca/sites/default/files/2020%20UBC%20CCAR_20%20May%202021.pdf.

[15] UBC SUSTAINABILITY "UBC Climate Change Accountability Report 2021", https://sustain.ubc.ca/sites/default/files/2021%20UBC%20Climate%20Change%20Accountability%20Report%20%28CCAR%29.pdf.

[16] UBC SUSTAINABILITY "UBC Climate Change Accountability Report 2022", https://sustain.ubc.ca/sites/default/files/files/2022_CCAR_UBC-%20Full%20Report.pdf.

[17] UBC BOARD OF GOVERNORS "UBC Board of Governors Agenda Packages and Minutes June 2022", https://bog.ubc.ca/meeting-agenda-minutes/2022-agenda-packages-and-minutes/june-2022/.

[18] UBC PAIR "Undergraduate Experience Survey 2022", https://pair.cms.ok.ubc.ca/wp-content/uploads/sites/145/2022/09/UES-2022-TOP-2-UBC-Vancouver.pdf.

[19] UBC PAIR "Undergraduate Experience Survey 2019", https://pair.cms.ok.ubc.ca/wp-content/uploads/sites/145/2020/07/UES-2019-Full-Distribution-UBC-Vancouver-DOMISI.pdf.

[20] UBC PAIR "Undergraduate Experience Survey 2021", https://pair.cms.ok.ubc.ca/wp-content/uploads/sites/145/2021/07/UES-2021-Full-Distribution-Vancouver-Dom-ISI.pdf.

[21] UBC "UBC 2023/2024 Budget", https://finance.ubc.ca/sites/finserv.ubc.ca/files/2023_24_UBCBudgetReport_Full_v5.pdf.

[22] UBC "UBC 2021/2022 Budget", https://finance.ubc.ca/sites/finserv.ubc.ca/files/UBC_2021-22_Budget.pdf.

[23] BANK OF CANADA "Bank of Canada Inflation Rate, Oct. 2023", https://www.bankofcanada.ca/.

[24] C. PERRY, K. C. CRELLIN "The Precise Management Meaning of a Shadow Price", DOI: https://doi.org/10.1287/inte.12.2.61.

[25] MACHINELEARNINGGEEK.COM "Sensitivity Analysis in Python", https://machinelearninggeek.com/sensitivity-analysis-in-python/.