

Agent-Based Network Analysis of Sustainable Tourism in Juneau, Alaska

2025 MCM Problem B

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1 Summary

Overtourism in Juneau, Alaska, underscores the environmental, social, and infrastructural challenges posed by unsustainable tourism. With a population of just 33,000, the city hosted 1.6 million cruise passengers in 2023, generating significant revenue but straining infrastructure and depleting natural resources like the shrinking Juneau Icefield. This study uses two complementary **agent-based models (ABMs)** to evaluate and optimize tourism sustainability.

Our *Lotus Hotel Model* provides a baseline by simulating random tourist movements without preferences or capacity constraints, exposing issues such as overcrowding and environmental stress. The **Optimized Model**, on the other hand, incorporates **agent-based preferences** and a **utility function** that accounts for factors like travel distance, crowding, weather, and tourist interests. Both models use a **graph representation** of Juneau, where **nodes** represent points of interest (POIs) with attributes such as capacity, **environmental impact**, and **revenue potential**, and **edges** represent travel times calculated using **Dijkstra’s algorithm**.

The **Optimized Model** significantly reduces the **carbon footprint** and mitigates social impacts by distributing visitors more evenly across POIs, while maintaining stable revenue levels. The **utility function**, defined as $\text{Utility} = \text{Preference Bonus} - \text{Travel Penalty} - \text{Crowd Penalty} - \text{Weather Penalty}$, is central to these improvements. Simulations conducted over 30 days reveal that the model is highly sensitive to tourist numbers, with rising visitor counts amplifying social and environmental costs. Revenue, however, remains less sensitive to optimization, as the utility function does not prioritize high-revenue nodes.

In conclusion, the **optimized agent-based model** demonstrates the potential for sustainable tourism by reducing environmental and social impacts without significantly compromising revenue. Future research should expand the network size and incorporate dynamic tourist flows for greater realism.

Keywords

Overtourism, **agent-based model**, **Dijkstra’s algorithm**, **optimization**, **utility function**, sustainability, weighted parameters

2 Introduction

2.1 Background

The phenomenon of *overtourism*—where the excessive presence of tourists negatively affects local communities, ecosystems, and cultural landmarks—has become increasingly prominent in many tourist ‘Hot spots.’ Ironically, one such ‘Hot spot’ is Juneau, Alaska, with a population of approximately 33,000, hosted a record 1.6 million cruise passengers in 2023, bringing an estimated 375 million in revenue. [6] While surges in tourism are often accompanied by an influx in local spending, they have the potential to cause significant strain on city infrastructure, natural resources, and local well-being.

A focal point of Juneau’s tourism and ongoing local contention is the Juneau Icefield, located on the border between Alaska and British Columbia, which has experienced significant glacier loss in recent years. As of 2019, the icefield comprised 1050 glaciers covering an area of 3816.3 km³ with an ice volume of 1051.1 ± 301.7 km³. Between 1770 and 2020, the total ice loss was 315.3 ± 237.5 km³, equivalent to slightly less than 25 percent of the initial ice volume. This acceleration is particularly concerning, as the rate of ice loss doubled in the most recent decade compared to the previous period[5] [3].

Time Period	Annual Rate of Change (km ³ per year)
1770-1979	0.65 to 1.01
1979-2010	3.08 to 3.72
2010-2020	5.91

Table 1: Annual Rate of Change in Volume over Different Time Periods

Survey Year	Cruise Passenger Volume (in Thousands)	% Change
1995	380.6	-
1998	568.5	+49%
2002	741.5	+30%
2006	951.4	+28%
2019	1305.7	+37%
2022	1167.0	-11%
2023	1650.0	+41%
Change 1995-2023		+334%

Table 2: Juneau Cruise Passenger Volumes in Survey Years

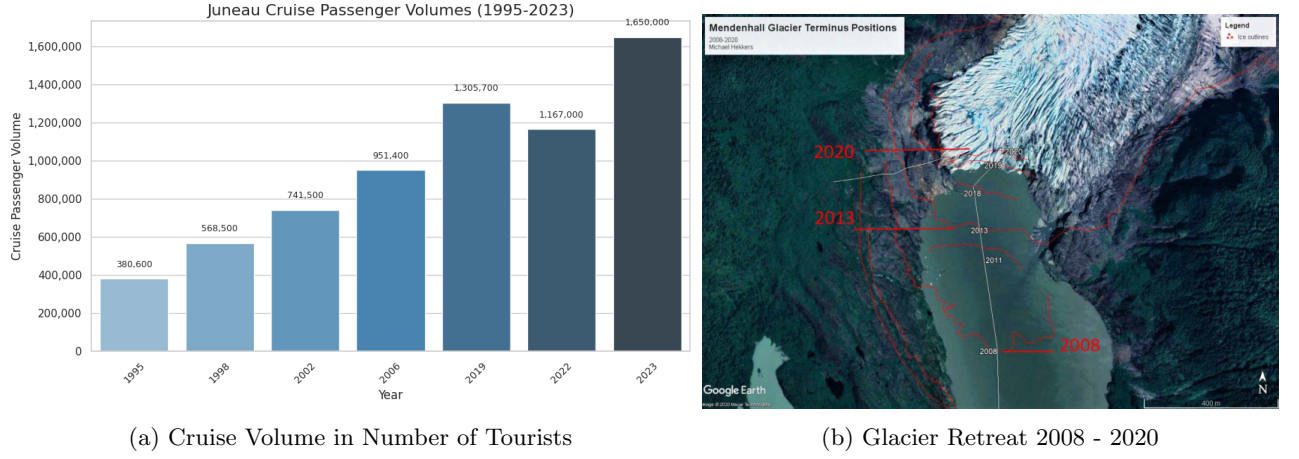


Figure 1: Cruise Tourist Volumes and Glaciers in Juneau.

2.2 Our Approach

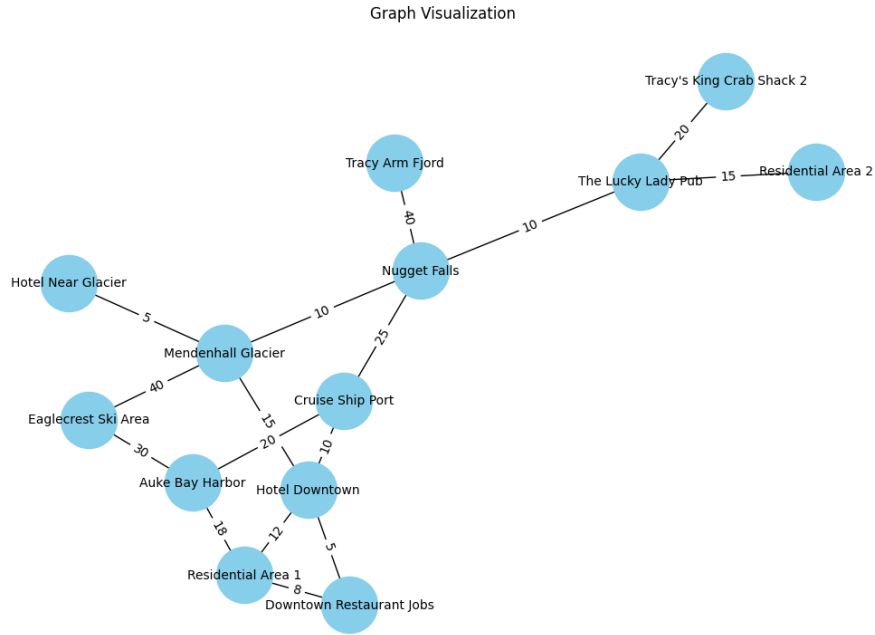


Figure 2: Graph Representation of Juneau

To address the challenges of sustainable tourism in Juneau, we developed and implemented a model based on two complementary methodologies: Random Walk which we refer to as the - *Lotus Hotel* - and an *agent preference-based optimization framework*. The *Lotus Hotel Model* serves as the

baseline, simulating random tourist behavior to understand system dynamics under current conditions, while the optimized agent-based model incorporates individual preferences to simulate realistic sustainability outcomes.

The underlying framework for both methodologies relies on representing Juneau as a weighted graph, where points of interest (POIs) such as attractions, accommodations, and community spaces are modeled as nodes, and distances between them are characterized by travel time weights. Each node is characterized by parameters representing capacity constraints (e.g., restrooms, parking, and cultural thresholds) and its impacts on economic revenue, social stress, and environmental degradation.

The network-based structure of these models provides an intuitive framework for capturing the spatial and logistical dimensions of tourism, allowing us to quantify the flow of visitors, node-specific impacts, and the consequences of exceeding capacity thresholds. Similar agent-based models have been applied to simulate urban dynamics [7], optimize park management [8], and design sustainable tourism strategies in fragile ecosystems [1]. Our approach builds on these precedents by adapting ABM to the unique context of over tourism in Juneau.

2.2.1 The Lotus Hotel

The *Lotus Hotel Model* simulates entirely random tourist movements across nodes without incorporating any decision-making process or specific agent preferences. Tourists move through the network arbitrarily, oblivious to external factors such as weather, node attractiveness, or travel times. This purely random approach provides a baseline for understanding the impacts of unmanaged and chaotic tourist behaviors. It highlights critical issues, such as bottlenecks at popular points of interest (POIs), overburdened infrastructure, and environmental stress. The insights gained from the *Lotus Hotel* serve as a benchmark for comparison and inform the constraints for the optimized framework.

2.2.2 Agent-Based Preferences

Building on the insights from the *Lotus Hotel*, our optimization framework introduces agent-based decision making to model tourists and locals with distinct behavioral archetypes. Tourists: cruise shippers, budget travelers, and nature enthusiasts are each initialized with varying home and preference POIs. Agent movements are dictated by schedules: agents must start each day at their designated home node. Before deciding where to move throughout the day, before ultimately making it back to their home node. Mid-Day decisions are guided by a decision-making algorithm that balances individual preferences alongside node specific information.

Utility optimization is on agent by agent basis with individual agents seeking to maximize a composite utility score:

$$\text{Utility} = \text{Preference Bonus} - \text{Travel Penalty} - \text{Crowd Penalty} - \text{Weather Penalty}$$

This score incorporates factors such as tourist preferences, overcrowding, and weather events. By explicitly modeling agent preferences, the optimization framework achieves a more balanced distribution of tourists across POIs, mitigating the issues of overburdened nodes identified in the *Lotus Hotel Model*.

3 Assumptions and Justifications

- There is a fixed, unchangeable influx of tourists; we will figure out how to host them optimally.

- Model in discrete time, $\Delta t = 3\text{hours}$
- Skip nighttime
- The number of locals does not change in a month, i.e. locals do not move away from or to Juneau within a 30 day period.
- Tourists arrive randomly every day and stay for a duration of 1 to 4 days.

4 Sustainability Scoring (Mathematical Approach)

4.1 Sustainability Score

Sustainable tourism accounts for the environmental, social, and economic impacts that tourism has on a city. To find the optimal values and thresholds that will allow for a careful balance of tourism and sustainability, we have developed a sustainability score.

4.1.1 Variables

x_{ij} : the fraction or percentage of tourists assigned to node i at time step j

$$x_{ij} = \begin{cases} 1 & \text{if all tourists are at node } i \text{ at time } j \\ 0 < x_{ij} < 1, & \text{if a fraction of tourists are at node } i \text{ at time } j \\ 0, & \text{if no tourists are at node } i \text{ at time } j \end{cases}$$

$$x_{ij}^k = \begin{cases} 1 & \text{if all tourists of type } k \text{ are at node } i \text{ at time } j \\ 0 < x_{ij}^k < 1, & \text{if a fraction of tourists of type } k \text{ are at node } i \text{ at time } j \\ 0, & \text{if no tourists of type } k \text{ are at node } i \text{ at time } j \end{cases}$$

4.2 Sustainability Score Calculation for Potential Optimization

Our sustainability score is a mathematical model designed to assess and optimize the sustainability of tourism in a city, accounting for the three, primary impacts of tourism: economic, environmental, and social. By maximizing the objective function, we can then determine the ideal allocations of resources and tourists to maintain sustainable tourism. Alternatively, we can minimize the cost that tourism has on the city to achieve the same results.

When implementing the model, we considered two models: a simplistic model in which agents moved randomly and a more complex model in which tourist agents had preferences for nodes.

4.2.1 Baseline Sustainability Score

The baseline objective function for calculating the sustainability score does not account for the individual type – Cruise Day Tripper, Budget Traveler, Nature Lover, or Local – and focuses on the general resource allocation. This means that there is no preference when determining which node the agent moves to within the model. Below we have both the formulas to either maximize the

Variable	Description
α	Weight assigned to revenue impact
β	Weight assigned to environmental impact
γ	Weight assigned to social impact
K	Total number of types of tourists ($K = 4$ in this model)
k	Type of indiv. corresponding to the list below: 1. Cruise Day Tripper 2. Budget Traveler 3. Nature Lover 4. Local
N_{tour}	Number of tourists at some node i
$N_{\text{tour},k}$	Number of tourists for a given tourist type k at some node i
C_i	Node capacity
E_i	Environmental Impact
S_i	Social Impact
R_i	Revenue Impact
U_{vi}	Likelihood or probability that a tourist will travel from node v to node i
$P_{i,k}$	Probability that tourists of type k will visit node i
T_{vi}	Time to travel from a visited node (v) to a new node (i)
Cr_i	Current crowding at node i
W	Weather
CF	Carbon Footprint

Table 3: Table of Variables and Descriptions

sustainability or minimize the impact, however, both can be used to determine the ideal parameters to maintain sustainable tourism.

$$\text{Maximize: } \sum_{i=1}^N \sum_{j=1}^T (\alpha R_i x_{ij} - \beta E_i x_{ij} - \gamma S_i x_{ij})$$

Alternatively:

$$\text{Minimize: } \sum_{i=1}^N \sum_{j=1}^T (\beta E_i x_{ij} + \gamma S_i x_{ij} - \alpha R_i x_{ij})$$

where:

N : Number of nodes.

T : Total number of time steps.

Constraints

1. With the model, each individual (agent) is assigned to exactly one node at any given time step j for T total time steps:

$$\sum_{i=1}^N x_{ij} = 1, \quad \forall j \in \{1, \dots, T\}$$

- Each node has a set capacity of C_i and the number of individuals should not exceed the node capacity. If there is an instance in which the number of total individuals exceeds the total node capacities then we will penalize it accordingly.

$$\sum_{j=1}^T x_{ij} \cdot N_{\text{tour},i} \leq C_i, \quad \forall i \in \{1, \dots, N\}$$

- U_{vi} is the preference to move from a visited node to a new node i . However, for the baseline model, all individuals will have the same preference value. The travel time, amount of crowding, and current weather will still be variable.

$$\begin{aligned} U_{vi} &= \text{preference} - \text{travel time} - \text{crowding} - \text{current weather} \\ &= P_i - T_{vi} - C_i - W. \end{aligned}$$

4.2.2 Calculating R_i (Revenue Impact)

For the Revenue Impact calculation in the baseline model, we assume that if the individual (agent) visits the node, they will spend an average dollar amount at the node. We set that value to be r_i , the revenue gained from one visitor. We also include a factor L_i to determine the amount of revenue that will be retained by the local government to not only sustain the city's operations but also future tourism. The Revenue Impact for the baseline equation is modeled as follows:

$$R_i = r_i \cdot L_i$$

where:

r_i : Revenue gained from one visitor.
 L_i : Revenue retained by the local government

4.2.3 Calculating E_i (Environmental Impact)

Within the Environmental Impact calculation, we begin by accounting for an individual's baseline daily carbon footprint, irrespective of travel activities. To this, we add the carbon footprint associated with traveling between nodes, represented by D_{vi} , which denotes the distance traveled from a previously visited node (v) to a new node (i). Based on the travel distance, the optimal mode of transportation is determined. The carbon footprint from travel is then calculated by multiplying the distance traveled (D_{vi}) by the carbon emission factor associated with the chosen mode of transport. The equation for environmental impact is modeled below:

$$E_i = (CF_{\text{baseline}} \cdot D_{vi} \cdot CF_{D_{vi},M})$$

where:

CF_{baseline} : Baseline carbon footprint emitted daily by a person.
 D_{vi} : Distance from node v to node i .
 M : Mode of transportation (car, boat, plane, bus, biking, walking, etc.)
 $CF(D_{vi}, M)$: Carbon footprint determined by the distance traveled and mode of transportation.

4.2.4 Calculating S_i (Social Impact)

In the Social Impact calculation, we assume that the preferred location of stay and the daily disruption caused are consistent across different individual types. The duration of an individual's stay is randomized between 1 to 4 days in both models. Additionally, to address potential overcrowding, a penalty is applied whenever the number of visitors exceeds a node's capacity. The equation to model the Social Impact at one particular node is modeled below:

$$\begin{aligned} S_i &= \left(\sigma_{stay}(i) + \sigma_{visit}(i) + \sigma_{overflow}(i) + \sigma_{disruption}(i) \right) \\ &= \left(P_{stay} \cdot \Delta_{stay} + \frac{\text{Visitors}_i}{C_i} + \max(0, \text{Visitors}_i - C_i) \cdot \Delta_{overflow} + \Delta_{disruption} \right) \end{aligned}$$

where:

$\sigma_{stay}(i)$: Likelihood that a tourist of type k stays at a type of accommodation (node i) and its associated disruption to the city.

$\sigma_{visit}(i)$: Social cost based on visitors at node i .

$\sigma_{overflow}(i)$: Overflow cost if the number of visitors exceeds the capacity.

$\sigma_{disruption}(i)$: The amount of disruption an individual causes to the city.

If the tourist type is "local", we assume this value to be 0.

4.2.5 Sustainability Score with Individual Type Included (Tourists vs Locals)

The optimized model accounts for varying tourist preferences. For instance, a Cruise Day Tripper may prefer to stay within the town and closer to the port, whereas a Nature Lover may be more inclined to travel to more distant tourist destinations. This variation is reflected in the impact scores through $P_{i,k}$, which represents the likelihood that a tourist of type k visits a specific node.

$$\text{Maximize: } \sum_{k=1}^K \sum_{i=1}^N \sum_{j=1}^T (\alpha R_i x_{ij}^k - \beta E_i x_{ij}^k - \gamma S_i x_{ij}^k)$$

Alternatively:

$$\text{Minimize: } \sum_{k=1}^K \sum_{i=1}^N \sum_{j=1}^T (\beta E_i x_{ij}^k + \gamma S_i x_{ij}^k - \alpha R_i x_{ij}^k)$$

Constraints with Tourist Type (k) Considered

1. Each individual of type k will be assigned to exactly one node at a given time:

$$\sum_{i=1}^N x_{ij}^k = 1, \quad \forall j \in \{1, \dots, T\} \quad \forall k \in \{1, \dots, K\}$$

2. Each node has a set capacity of C_i and the number of individuals should not exceed the node capacity. If there is an instance in which the number of total individuals exceeds the total node capacities then we will penalize it accordingly in the impact equations.

$$\sum_{j=1}^T x_{ij}^k \cdot N_{\text{tour},i} \leq C_i \quad \forall i \in \{1, \dots, N\}, \forall j \in \{1, \dots, T\}, \forall k \in \{1, \dots, K\}$$

3. U_{iv} : The preference score U_{vi} is slightly different as the preference is not longer uniform for all individuals. The preference of a location (node i) is now determined by the tourist type.

$$\begin{aligned} U_{vi} &= \text{preference} - \text{travel time} - \text{crowding} - \text{current weather} \\ &= P_{i,k} - T_{vi} - C_i - W \end{aligned}$$

Calculating R_i (Revenue Impact)

For the Revenue Impact calculation, we assume that the average expenditure per person at a given node type remains consistent. Specifically, a visitor is expected to spend r_i at a node they visit, with the revenue primarily determined by the node type rather than individual spending behavior. Additionally, the retained revenue (L_i) is assumed to remain constant between the baseline and optimized models. The primary difference between the optimized and the baseline model is that we now account for the likelihood that an individual of type k will visit node i and spend money. The equation modeling this is below:

$$R_i = \sum_{k=1}^K N_k \cdot P_{i,k} \cdot r_i \cdot L_i$$

where:

- $P_{i,k}$: Likelihood that a tourist of type k visits some node .
- r_i : Revenue gained from one visitor.
- L_i : Revenue retained by the local government

4.2.6 Calculating E_i (Environmental Impact)

In the Environmental Impact calculation, we assume a baseline daily carbon footprint ($CF_{baseline}$) emitted by an average individual, along with additional emissions resulting from the distance traveled and the mode of transportation ($CF_{D_{vi},M}$). The carbon footprint varies depending on the mode of transport, as vehicles like cars produce significantly more emissions compared to walking. Furthermore, incorporating node preferences ($P_{vi,k}$) based on node types provides a more accurate representation of tourist behavior. For instance, Nature Lovers are more likely to travel longer distances to visit attractions such as glaciers, whereas Cruise Day Trippers may prefer destinations closer to the port. The equation incorporating the agent preferences is modeled as follows:

$$E_i = \sum_{k=1}^K N_k \cdot (CF_{baseline} \cdot P_{vi,k} \cdot D_{vi} \cdot CF_{D_{iv},M})$$

where:

- $CF_{baseline}$: Baseline carbon footprint emitted daily by a person.
- $P_{vi,k}$: Probability that a tourist of type k will travel from visited node v to node .
- D_{vi} : Distance from node v to node .
- M : Mode of transportation (car, boat, plane, bus, biking, walking, etc.)
- $CF(D_{vi}, M)$: Carbon footprint determined by the distance traveled and mode of transportation.

Calculating S_i (Social Impact)

In the Social Impact calculation with agent preferences, we accounted for the likelihood that individuals would stay at specific types of accommodations. For instance, Locals are expected to reside in residential areas, while Cruise Day Trippers are likely to remain on the cruise ship.

In the baseline calculation, we assumed that the preferred location of stay is the same across all individual types. In contrast, the optimized calculation considers that individuals have distinct preferences for their accommodations, each contributing different levels of disruption to the city. The duration of stay in both models is still randomized between 1 to 4 days. Additionally, we incorporated the same penalty for exceeding the node's capacity and assume that the disruption caused by each tourist remains uniform. The equation modeling the Social Impact with consideration for agent preferences is as follows:

$$\begin{aligned}
S_i &= \sum_{k=1}^K N_k \cdot \left(\sigma_{stay,k}(i) + \sigma_{visit}(i) + \sigma_{overflow}(i) + \sigma_{disruption}(i) \right) \\
&= \sum_{k=1}^K N_k \cdot \left(P_{stay,k} \cdot \Delta_{stay} + \frac{Visitors_i}{C_i} + \max(0, Visitors_i - C_i) \cdot \Delta_{overflow} + \Delta_{disruption} \right)
\end{aligned}$$

where:

$\sigma_{stay,k}$: Likelihood that a tourist of type k stays at a type of accommodation (node i) and its associated disruption to the city.

$\sigma_{visit}(i)$: Social cost based on visitors at node i .

$\sigma_{overflow}(i)$: Overflow cost if the number of visitors exceeds the capacity.

$\sigma_{disruption}(i)$: The amount of disruption an individual causes to the city.

If the tourist type is "local," we assume this value to be 0.

5 Computational Modeling

5.1 Our Network

Using NetworkX library for Python [2], we create a weighted graph with nodes representing points of interest (POIs), named after real locations in Juneau, Alaska.

Each POI has a name, a type, coordinates, values for environmental and social impact per visitor, and restroom, parking, and cultural capacities. See appendix for examples.

- Type: there are 6 categories for POIs: Cruise_port, tourist_site, hotel, residential, workplace, restaurant
- Coordinates: (x,y)
- Social Impact: When high, means that each visitor causes a strain on resources at the location (restrooms, parking, overall culture of the location). A low score means that the location has a high capacity for visitors and having more visitors positively impacts the place's culture.
- Environmental Impact: This score represents a theoretical amount of environmental damage per visitor to an establishment. e.g. a hotel would have a higher environmental impact than residential household.

- Restroom capacity: an estimated number of restroom stalls for that location. Affects the daily social impact score if the number of visitors exceeds the restroom capacity.
- Parking capacity: an estimated number of parking spots at a location.
- Cultural capacity: a somewhat opinion-based score for the number of people who can be there while maintaining the intended level of quality of the experience. i.e. This could be determined based on polling data from visitors of a POI.

5.1.1 Agents

Agents, including locals and tourists, move throughout the network and cause changes to scores and their own attributes. Each agent object of class Agent has the following attributes:

- Agent Type: Either a local or a tourist. There are three types of tourists: cruise day-tripper, nature-lover, and budget traveler. The three types of tourists differ only in their preferences, e.g. nature-lovers prefer tourist sites, while cruise day-trippers prefer a restaurant.
- Location: An agents current location is the node they're at, which is updated as they traverse the network.
- Home: Where they go in the evening. Locals go to a residential area, and tourists go to a hotel or back to the cruise ship.
- Workplace: Only locals go to the workplace, and they do so in the morning.
- Arrival Day: The day that a tourist is meant to "arrive" at the beginning of a simulated month. They are not moved around or counted as in Juneau before their arrival day occurs.
- Stay Duration: A value $[1, 4]$ that represents the average stay duration of vacationers in Juneau[4]. They leave the simulation after their stay is up. The stay duration is not counted for locals.
- Days Count: The amount of days a tourist has been in Juneau.

5.2 Lotus Hotel Simulation

The Lotus Hotel Simulation, affectionately named after the chaotic, alluring Lotus Hotel and Casino from Percy Jackson and the Olympians, is our control level where tourists and locals are allowed to move to any nodes they prefer regardless of location capacity or carbon footprint from travel. We examine each agent's list of preferences and randomly select a node to travel to, including its current node. There are no limitations on capacity or optimization for environmental or social impact in choosing a node, but the move function is optimized for the shortest path to whatever the chosen node is. All agents leave their homes in the morning and go back home in the evening. Locals go to their workplace, but are free to go anywhere else in the midday or afternoon.

This is meant to represent tourists and locals movement without limitations or government interference. We add up the total carbon footprint for the day from everyone's travels. We count the social, cultural, and environmental impact from each of the nodes, which comes from how many visitors each of them had. We find that these totals are rather high on average over a 30-day month. Next, we will optimize tourist movement to try to reduce these averages.

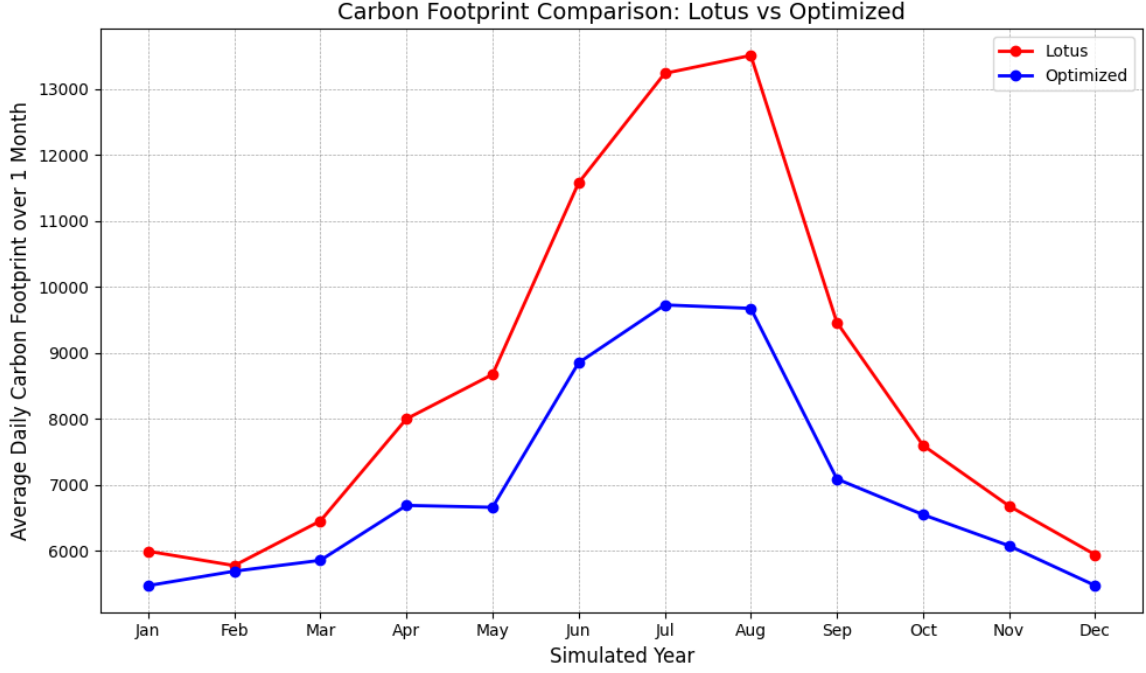


Figure 3: Carbon Footprint Comparison Between Lotus and Optimized Models

- First, we initialize total and daily values for environmental impacts, social impacts, revenues, locally retained revenues, and agent counts to 0.
- Loop for 30 days to represent a month
- Count the number of tourists who are currently in Juneau i.e. they have arrived already and they haven't left yet. Also count the number of locals (this remains the same throughout the simulation).
- Although our for loop goes by day, we then break up the day into 4 segments so that our Δt is actually 3 hours, and we skip the nighttime. We run another loop inside the previous loop for morning, midday, afternoon, and evening.
- Here, we allow agents to move to their preference-based, randomly-selected node and count their carbon footprint from their travels.
- Their movement is optimized for smallest distance using Dijkstra's Algorithm []
- For each node that is traveled to, we increment their impact and revenue values based on the number of times it is visited.
- Finally, we update the number of days the tourists have been in town by one and reset for the next day.

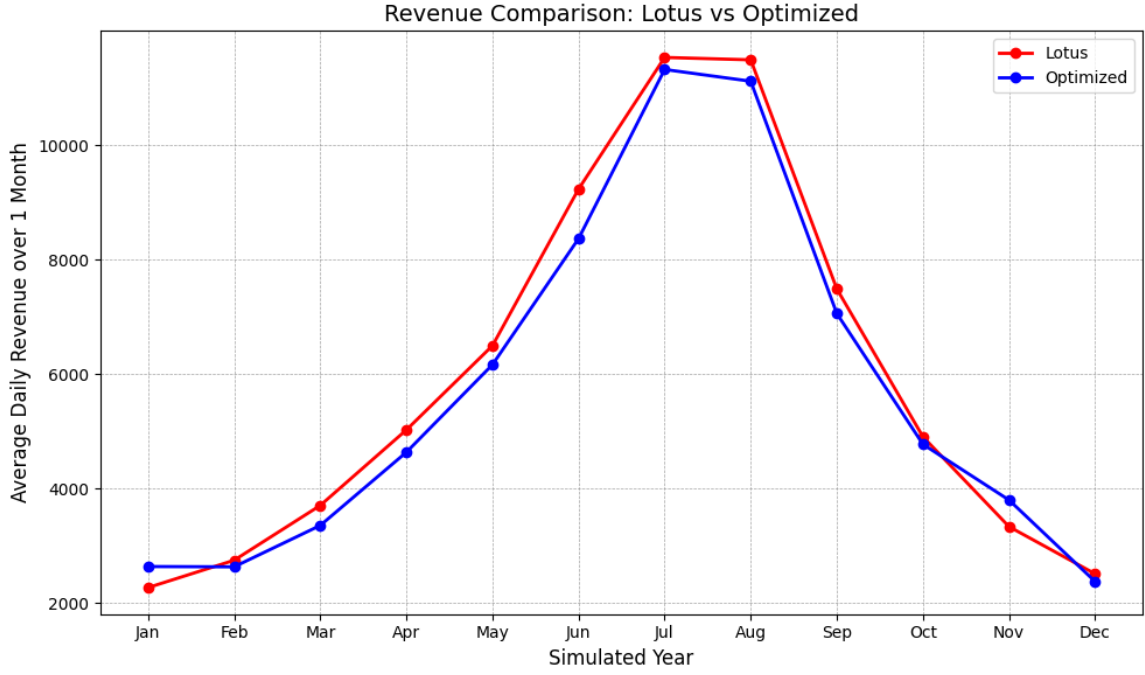


Figure 4: Revenue Comparison between Lotus and Optimized Models

5.3 Optimized Model

The Optimized simulation works similarly to the Lotus Hotel simulation. The main difference is that tourists no longer move semi-randomly. Now, they rely on a “utility” function to decide which node to move to next. Locals still move as randomly as they did in the Lotus simulation.

5.3.1 The Utility Function

The Utility function determines a single POI’s utility to an individual agent, taking into account:

- **Preference Bonus:** If a POI is in an agent’s preference list, it adds a bonus to the utility score
- **Travel Penalty:** Check the travel time, or the sums of the weights along the shortest path to an edge, for each edge and multiply by 0.5.
- **Crowd Penalty:** Added if the parking capacity is below 50 spots. *This can be expanded to include restroom and cultural capacities too.
- **Weather Penalty:** Tourist site desirability is dependent on weather conditions that day. A random number generator provides a value (0.5, 1.0) which is weighted and subtracted from the utility.

We use the equation from before:

$$\text{Utility} = \text{Preference Bonus} - \text{Travel Penalty} - \text{Crowd Penalty} - \text{Weather Penalty}$$

The Optimized model works much like the Lotus Hotel model, except that, for each agent, it loops through all nodes and determines which has the highest utility value and moves the agent there. The movement of locals is implemented exactly the same way as in the Lotus Model.

6 Model Sensitivity Analysis

To create a model that was manageable, we simplified a map of Juneau to only 13 nodes. Because the model does not accurately represent the size of Juneau, the model is sensitive to very high and more realistic influxes of tourists. However, because the real Juneau is very small and accommodates far more tourists than its population, we keep our smaller-scale model as is and note that it cannot accurately represent the behavior when the amount of tourists is too large.

The daily social impact is also sensitive to the amount of tourists. The daily social impact is incremented when the amount of visitors exceeds the restroom, parking, and cultural capacities for the POI. Thus, these values become very high when there are too many tourists.

The revenue is not very affected by the optimization of the model. While optimization somewhat reduces the environmental and social impact of the same amount of tourists, only barely reduces the total average revenue, as seen in [Figure 4](#). This is because the optimizing function (the aforementioned “utility” function) does not set preference for establishments with a higher revenue per visitor value. Thus, the local retention is also not sensitive to optimization.

7 Further Discussion

7.1 Model Improvements

In the future, we can expand the map to accommodate more tourists and represent more locations. We can write a function to generate locations to generalize to different cities based on their needs. We experimented briefly with scraping POIs from Google Maps, but ultimately decided that it was beyond the scope of our intended analysis.

To further enhance the model, we can explore different weights for α , β , and γ to determine the maximum sustainability score. Depending on what is prioritized in the city of Juneau, the weights can be adjusted to emphasize environmental conservation, economic growth, or minimizing social disruption. For example, a higher weight on β could reflect a greater focus on reducing environmental impact, while a higher α value might prioritize maximizing revenue from tourism. By calibrating these weights to align with the city’s specific goals, we can better tailor the sustainability score to represent the desired balance among economic, environmental, and social objectives. Due to the limited timeframe, we were able to implement our impact equations to calculate the average economic, environmental, and social impacts when we have randomized behavior and preferences. However, we have yet to polish the full sustainability score function and experiment with different weighted values. Finally, we could implement a sustainability score that encompasses all of the different scores (see Appendix). This would be something to consider in future implementations, and can be adjusted according to the city of Juneau’s needs at the time.

We did not have time to implement an all-encompassing sustainability score, although we wrote plans and equations for it.

7.1.1 Nonlinear Representations to better fit the data (GAM)

In future implementations, it may be wise to incorporate nonlinear relationships into the model to better represent realistic behaviors of both tourists and locals. One way to execute this is to use Generalized Additive Models (GAMs), which are an effective way to combine both linear and nonlinear functions by using smoothing terms. Some nonlinear relationships can be observed in the model when, for instance, tourist behaviors and environmental impacts may exhibit exponential effects such as a sharp increase in disruption when tourist capacities are exceeded at specific nodes. Accounting for the nonlinear patterns, the model can better represent the real-world impacts and possibly improve its generalizability in new simulations.

Expanding our current model to become a GAM will also provide us with the flexibility to address additional factors like seasonality and spatial relationships. Tourist arrivals and local behavior often fluctuate seasonally corresponding to peak travel months. With smoothing functions, we may be able to model the temporal effects whereas spatial terms will be able to model the nonlinear impact of overcrowding nodes that are near popular tourist attractions rather than only at the attraction itself. This way, the model is also able to consider a compounded social disruption caused by tourists and locals. By considering and incorporating these interactions alongside the individuals' preferences the model will be able to reflect the more intricate decision making process of the individual groups.

While GAMs are great for representing realistic behaviors and interactions, due to the restrictive time limit and the variable nature and spontaneity of human behaviors, it is difficult to model this without concrete data sets. Ultimately, these improvements would be able to provide policymakers with even more valuable insights into identifying critical thresholds and implementing strategies to promote sustainable tourism while balancing the economic, environmental, and social needs of the city of Juneau, Alaska.

8 Conclusion

In order to address the challenge of over-tourism in Juneau, Alaska, we have developed a comprehensive framework to assess and optimize sustainable tourism. Our model integrates mathematical formulas and network analysis to account for the economic, environmental, and social impacts on the city.

By evaluating tourism sustainability through these three critical lenses, our model provides actionable insights to manage visitor influx while minimizing negative effects on the city. Simulations using the Lotus Hotel scenario and our optimized model highlight how strategic planning and targeted interventions can boost revenue, reduce environmental degradation, and mitigate social disruptions for the local community.

This framework is tailored to Juneau's current city layout and points of interest. It empowers local decision-makers to make informed choices about future infrastructure development, implementing capacity limits at points of interest, or optimizing eco-friendly transportation options. For example, the optimization insights identify high-impact areas to reduce crowding and enhance resource efficiency. The sustainability score can also be recalibrated over time to reflect changing conditions and adapt to the city's evolving goals and priorities.

We believe this model offers Juneau a practical path forward to manage tourism sustainably, preserving the city's natural beauty and community well-being. Its implementation would position Juneau as a leader in sustainable tourism, demonstrating how careful planning and innovation can balance economic growth with environmental stewardship and social harmony.

9 Letter to Tourist Council

Dear Members of the Tourist Council,

We are writing to you with great enthusiasm and deep awareness of the pressing issue of overtourism in Juneau. The influx of 1.6 million cruise passengers annually highlights the immense economic opportunity tourism brings, but it also underscores the strain on the city's infrastructure, natural resources, and community well-being. Recognizing this challenge, our team has developed an advanced simulation model that offers actionable solutions to optimize tourism management and foster sustainable practices in your city.

Our agent-based simulation models the movement and behavior of tourists through Juneau, comparing a baseline scenario of unmanaged tourism with an optimized model that incorporates tourist preferences and sustainability metrics. The results are compelling: when tourists followed optimized paths, we observed a significant reduction in carbon footprint with only minimal declines in revenue. By evenly distributing visitors across points of interest, the optimized model mitigates overcrowding, minimizes environmental degradation, and preserves the cultural integrity of Juneau's most cherished sites.

The cornerstone of this program lies in its focus on informed tourism. By educating visitors about their environmental and social impacts—and providing them with tools to make responsible travel decisions—we can empower them to contribute positively to Juneau's sustainability goals. Measures such as digital travel guides, informative signage, and incentivized eco-friendly behavior can amplify these effects.

We are confident that our model aligns with Juneau's aspirations to balance economic prosperity with environmental stewardship. We propose collaborating with the Tourist Council to build a tailored program based on our simulation, providing the tools and data-driven insights necessary to implement these strategies effectively. With your support, we can ensure that tourism continues to enrich the community while preserving the unique beauty and resources of Juneau for generations to come.

We look forward to the opportunity to contribute to the sustainability and prosperity of Juneau.

Sincerely,
This Team

References

- [1] M. Batty. Agents, cells, and cities: New representational models for simulating multiscale urban dynamics. *Environment and Planning A: Economy and Space*, 37(8):13, 2005.
- [2] A. A. Hagberg, D. A. Schult, and P. J. Swart. Exploring network structure, dynamics, and function using networkx. In G. Varoquaux, T. Vaught, and J. Millman, editors, *Proceedings of the 7th Python in Science Conference*, pages 11–15, Pasadena, CA, USA, 2008.
- [3] E. . E. Leader. Accelerating glacial melt in alaskan icefields raises concerns, 2025. Accessed: January 27, 2025.
- [4] Ordinary Adventures. Perfect three-day itinerary for juneau, alaska. Blog post, 2023. Accessed: 2025-01-26.
- [5] N. University. Alaska glacier melt accelerating, study finds, 2024. Accessed: January 27, 2025.
- [6] D. USA. Juneau city and borough, ak, 2025. Accessed: 2025-01-01.
- [7] W. Wimolsakcharoen, P. Dumrongrojwatthana, C. Le Page, F. Bousquet, and G. Trébuil. An agent-based model to support community forest management and non-timber forest product harvesting in northern thailand. *Socio-Environmental Systems Modelling*, 3:21, 2021.
- [8] J. Zelenka, M. Pásková, and M. Husáková. Agent-based modelling in visitor management of protected areas. *Sustainability*, 14(19):18, 2022.

10 AI Use Report

Citation for ChatGPT-4.0

OpenAI ChatGPT (Nov 5, 2023 version, ChatGPT-4.0)

Query1: *How to itemize with numbers*

Output:

To create a numbered list in LaTeX, use the ‘enumerate’ environment. Here’s an example:

```
\begin{enumerate}
  \item First item
  \item Second item
  \item Third item
\end{enumerate}
```

Output:

1. First item
2. Second item
3. Third item

Customizing the Numbering

You can customize the numbering style using the enumitem package. For example:

```
\begin{enumerate}[label=\arabic*.]
  \item First item
  \item Second item
  \item Third item
\end{enumerate}
\end{document}
```

Other Numbering Styles:

You can change label= to use different formats:

- \arabic*. for 1, 2, 3...
- \roman*. for i, ii, iii...
- \Roman*. for I, II, III...
- \alph*. for a, b, c...
- \Alph*. for A, B, C...

Query2: *How to have a table with multiple lines in one entry in LaTeX*

Output: To have multiple lines in a table entry in LaTeX, you can use the \newline command or \multirow from the multirow package. Here’s an example:

```
\begin{tabular}{|c|c|}
\hline
Column 1 & Column 2 \\
\hline
Row 1, Cell 1 & Row 1, Cell 2 \\
\hline
\end{tabular}
```