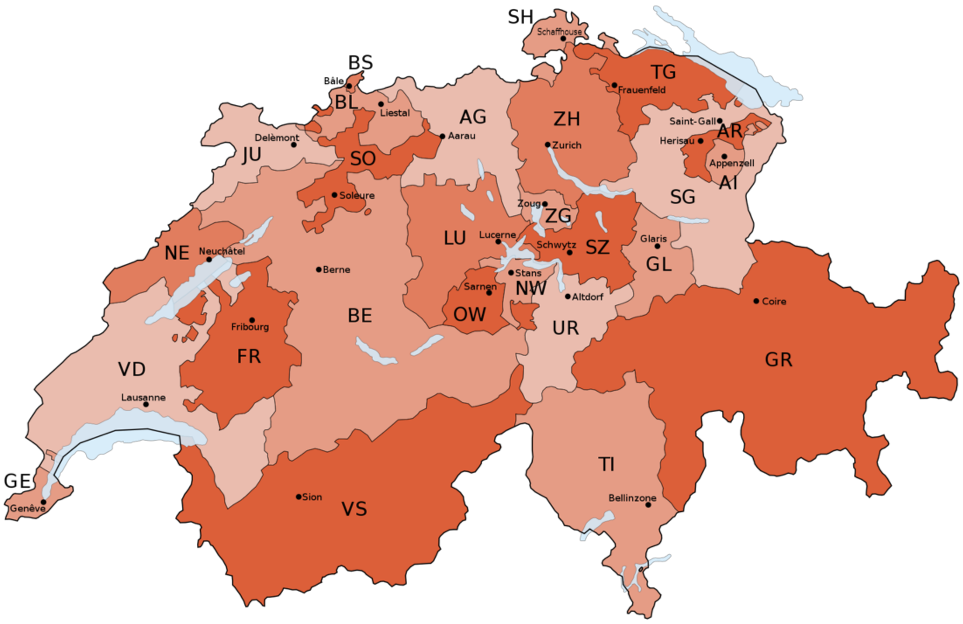

SUSTAINABLE LOGISTICS

Group n°1 Project report

Summary

This project report concerns the mobility of tourists in Switzerland. It has been realized with the aim of optimizing latter. This work was carried out within the academic framework of the "Sustainable Logistics" course of Mr. Olivier Gallay.

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HEC Lausanne - May 17th 2023

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1. Executive summary

This project presents a comprehensive strategy for improving tourism in Switzerland, considering tourist affordability, environmental sustainability, and travel efficiency. Known for its high standard of living and beautiful, well-preserved environment, Switzerland presents unique challenges for tourists due to its relatively high cost of living. Our goal was to overcome these challenges by creating optimized, cost-effective, and environmentally friendly travel plans using advanced algorithms.

We started by identifying the 10 most popular Swiss destinations on the Cap-Voyage website. These locations served as our main reference points, but our flexible model can incorporate any number of destinations and can be adapted to a wide range of traveler preferences. Our approach involved applying the Traveling Salesman Problem (TSP) and packing problem algorithms. The TSP algorithm helped find the most efficient route based on distance, time, and cost. We also used a variant of the knapsack algorithm that allows tourists to customize their travel plans based on their travel time and budget.

Interestingly, our results highlight the potential underutilization of the Swiss rail system by tourists, mainly due to high costs. The rail network is a great way to explore the country, but the pricing policy needs to be revised to make it more attractive and affordable for tourists. Our project therefore shows that important players in the Swiss tourism industry, such as SBB, need to rethink their pricing strategies. In this way, we can attract more tourists and promote a way of travel that is not only economical but also environmentally friendly.

This overview provides an overview of our project and its main results. Detailed recommendations based on comprehensive analysis are provided in the final section of the project report. Our goal is to help Swiss tourism authorities and tourists themselves to make informed decisions and achieve valuable, sustainable, and cost-effective travel experiences.

2. Describe the data collected or generated for the different input parameters (explain and motivate the reasons & motivations to implement data by ourselves)

Given our research objectives and the variety of information we needed, we decided to create our own data set from various sources. Thus, we created a data set with very complete data in terms of distance, time and travel costs for the car and the train, which are the two means of transport we selected to create this project.

Our data therefore includes for both car and train:

- The distances between all destinations (in km)
- Travel fares between all destinations (in CHF)
- Travel times between all destinations (in min/h)
- The tourist ratings for each destination

It is important to present one of our assumptions that no other means of transport has been included in our calculations. In addition, the calculations and algorithms have been established by systematically choosing only one of the two means of transport. We did not create a hybrid algorithm between these two means of transport.

3. Implementation tools

The whole project was coded in Python on Google Colab and to create the algorithms we started with; we used the OR-Tools library. In addition, for the more complex models that we will present later, we also used the Itertools package, another Python package that can be used on Colab and which allows the creation of extremely efficient iterator blocks. This library has allowed us to further support our analysis and to provide interesting tools for our analysis and for the conclusions that we can draw from it later. We also used the internal functions of the Python language in a general way to come to the obtained solutions.

4. Describe the objective function, constraints, taken hypothesis & assumptions about it.

4.1 First model: Optimizing distance to visit the top 10 destinations for both cars & trains

- Objective function

  The following problem can be considered as a VRP insofar as the notion of depot is included. But it is more like a TSP since the depot is only the starting and return point of the circuit and there is only one vehicle travelling through all the nodes. Therefore, the objective function can be defined as: Minimizing distance travelled by our vehicle in the TSP. This optimal value will be the shortest path to visit the 10 destinations we have chosen before. In addition, this first analysis will allow us to establish the environmental impact of train and car trips and to compare them.

- Constraints
  - The vehicle starts and ends at the depot node (node 9) and is unique.
  - Each node (location) can only be visited once.
  - The number of vehicles is limited to 1.
  - The distance between nodes is defined by the 'distance_matrix' data.

- Hypothesis & Assumptions
  - Only one vehicle is available for the routing problem.
  - The distance between any two nodes is symmetric, i.e., the distance from node A to node B is the same as the distance from node B to node A.
  - The distance between nodes is provided in the 'distance_matrix' as a complete graph, where each entry represents the distance between two nodes.

4.2 Second model: Optimizing time to visit the top 10 destinations for both cars & trains

- Objective function

  As in the first model, we are here in the presence of a TSP algorithm. This algorithm will also try to minimize the length of the route to connect the 10 destinations. However, this time the data in the distance matrix contains the travel times between the destinations and not the distances.

- Constraints
  - The vehicle starts and ends at the depot node (node 9) and is unique.
  - Each node (location) can only be visited once.
  - The number of vehicles is limited to 1.
  - The time required to travel between nodes is defined by the 'car_times' data.

- Hypothesis & Assumptions
  - Only one vehicle is available for the routing problem.
  - The time required to travel between any two nodes is symmetric, i.e., the time from node A to node B is the same as the time from node B to node A.
  - The time required to travel between nodes is provided in the 'car_times' as a complete graph, where each entry represents the time required to travel between two nodes.

4.3 Third model: Optimizing cost to visit the top 10 destinations by train

- Objective function

  As in the first models, we are here in the presence of a TSP algorithm. This algorithm will also try to minimize the cost of the route to connect the 10 destinations by train. The matrix is thus containing the travel costs (half-fare prices between all 10 destinations). We don't do this analysis for cars since car costs can be directly computed from the distance matrix.

- Constraints
  - The vehicle starts and ends at the depot node (node 9) and is unique.
  - Each node (location) can only be visited once.
  - The number of vehicles is limited to 1.
  - The cost required to travel between nodes is defined by the 'train_cost_matrix' data.

- Hypothesis & Assumptions
  - Only one vehicle is available for the routing problem.
  - The cost required to travel between any two nodes is symmetric, i.e., the cost from node A to node B is the same as the cost from node B to node A.
  - The time required to travel between nodes is provided in the 'train_cost_matrix' as a complete graph, where each entry represents the cost to travel between two nodes.

4.4 Fourth model: Finding the best car-route with given time constraint from the user

- Objective function

  Problem Type: We are here in presence of a kind of Packing Problem, it involves determining the optimal path to travel while satisfying given constraints, such as time, attraction interest, given visiting times & daily visiting expectations from user. The objective is to maximize the visit (in terms of attraction = TripAdvisor notes) according to those constraints.

- Constraints
  - The route starts and ends at the starting point.
  - Each destination (except the starting point) is visited exactly once.
  - The total time spent on traveling (including travel time and visit time) should not exceed the available days and daily visiting time constraints.
  - The route includes a subset of destinations to visit.
  - The route should maximize the total attraction score based on the attractions and attraction weights.
  - The order of destinations in the route matters.

- Hypothesis & Assumptions
  - The travel times between destinations are symmetric and fixed.
  - The visit times for each destination are given in hours and converted to minutes.
  - Attractions are represented by scores, indicating their level of attractiveness.
  - The attraction weight coefficient determines the importance of attraction scores in the route's calculation.
  - Daily visiting time is specified in minutes.
  - The starting point is one of the destinations, typically Zurich (main Swiss airport).
  - The input data, including travel times, attractions, visit times, attraction weight, available days, daily visiting time, and starting point, are valid and consistent.
  - The objective of the code is to maximize the total attraction score while meeting the given constraints.
  - Visit times for each destination remain constant and are not affected by external factors.
  - Attractions have fixed scores based on TripAdvisor average ratings.
  - The user-defined attraction weight accurately reflects the significance of attraction scores.
  - The daily visiting time remains constant throughout the trip.
  - There are no constraints on the visitation order of destinations, except those defined by the user.
  - Routes start and end at the same destination, which is determined by the user as the starting point, typically Zurich (main Swiss airport). We don't consider flight times/delays.

4.5 Fifth model: Finding the best route (car or train) with given cost constraint (budget) from the user

- Objective function

  We are here in presence of a variant of the Knapsack problem, it involves determining the optimal path to travel by train while satisfying given constraints, such as time, attraction interest, given visiting costs, willingness to pay for the half-tare card & daily visiting expectations from user. The objective function is to find the best route that maximizes the total attraction score while respecting the available budget constraint when travelling.

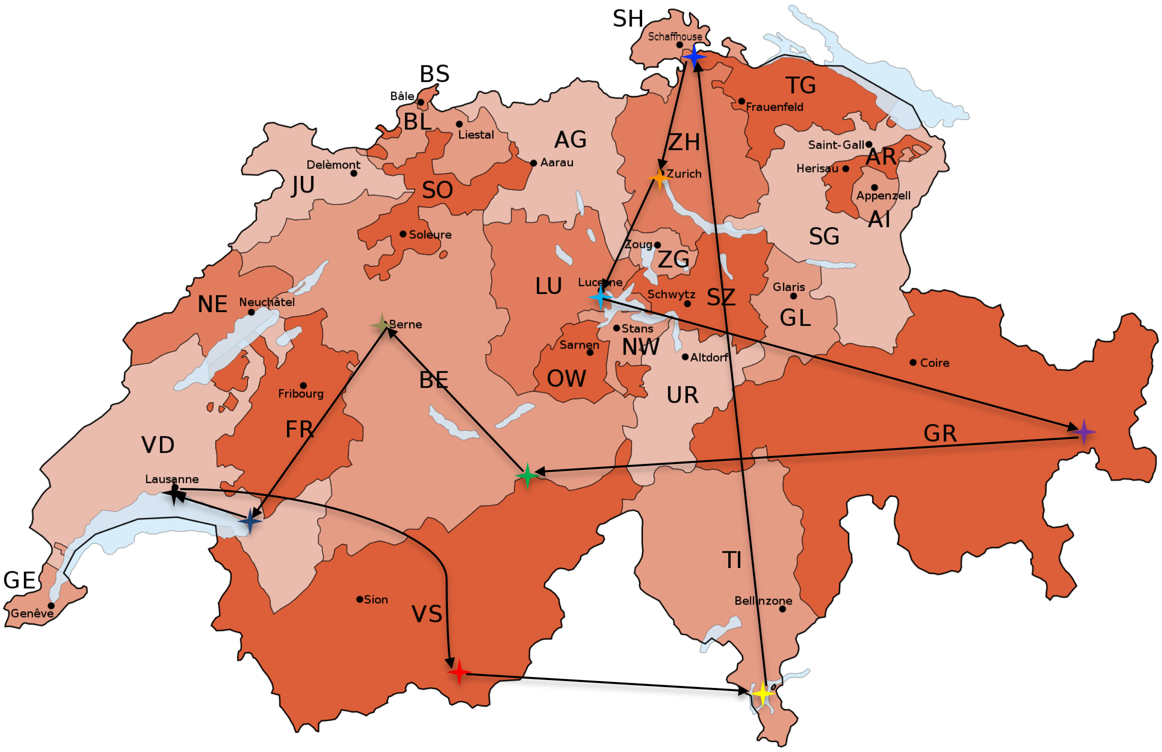
- Constraints
  - The route starts and ends at the starting point, which is typically Zurich (main Swiss airport).
  - Each destination (except the starting point) is visited exactly once.
  - The total cost of the trip, including travel costs and visit costs, should not exceed the available budget.
  - The attraction weight coefficient determines the importance given to attraction scores in the calculation of the route's score.
  - The starting point and input data (costs, visit_costs, attractions, attraction_weight, available_budget, starting_point) are provided with valid values and consistent with each other.

- Hypothesis & Assumptions
  - The travel costs between destinations are symmetric and fixed.
  - The visit costs for each destination are constant and independent of factors such as season or time.
  - The price to have access to half-fare train prices is included in the code
  - Attractions have fixed scores based on TripAdvisor average ratings.
  - The user-defined attraction weight coefficient accurately represents the importance of attraction scores in route planning.
  - The available budget is given in CHF (Swiss Francs).
  - All destinations can be visited in any order, and there are no dependencies or constraints on the visitation order, except those defined by the user.
  - Routes start and end at the same destination, typically Zurich (main Swiss airport).
  - The code aims to find the best route that maximizes the total attraction score while respecting the budget constraint.
  - The remaining budget after the trip is calculated as the available budget minus the total cost of the trip.
  - The travel costs and visit costs are fixed and known beforehand, without any variations based on external factors.
  - The attraction score is based on TripAdvisor's ratings for each location.
  - The route always starts and ends at the same location, which is determined by the user as the starting point.
  - The route can include any combination of destinations without constraints on the order or subset of destinations.
  - The best route is determined by the highest attraction score within the given budget constraint.
  - Costs are given *100 in the cost's matrix, otherwise the code isn't running

5. Result description and graphical representation

5.1 TSP: Comparison between car & train optimal routes

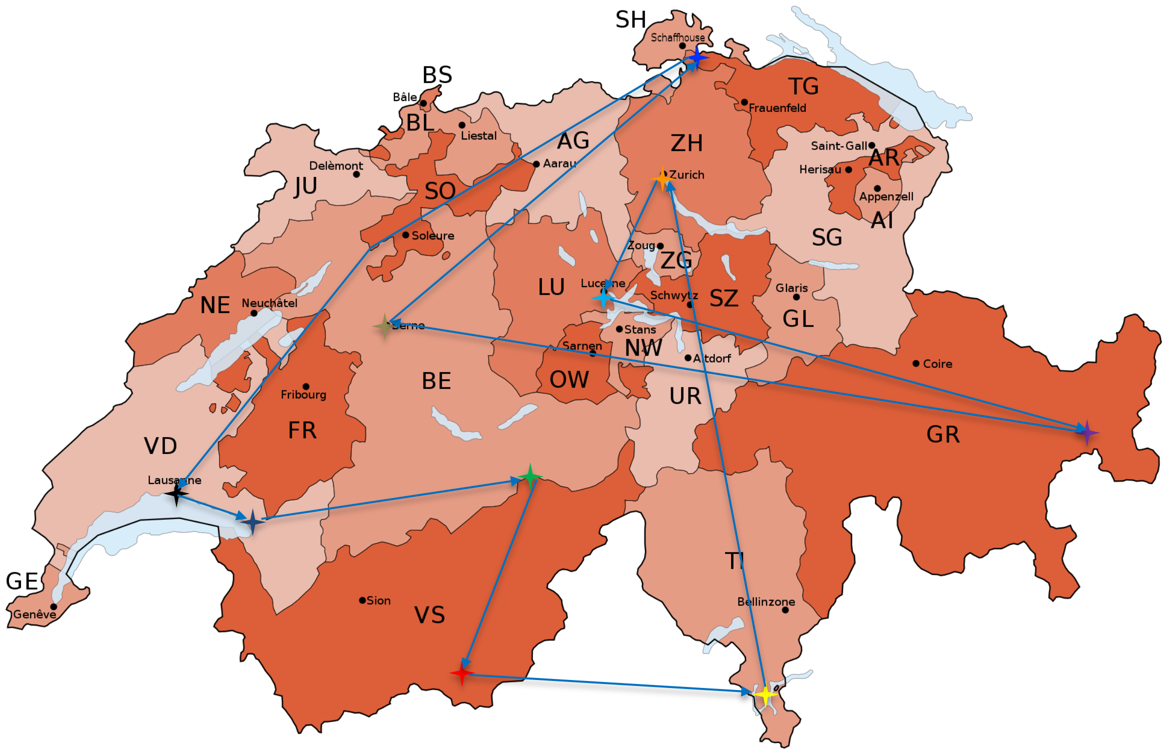
Car route: 14h50



: Observation platform of Gornergrat
: Chillon’s castle
: Jungfraujoch
: Schweizerischer national park
: Lemanic Lake in Lausanne

: Lugano’s town
: Berne’s town
: Lucerne’s town
: Rhin’s waterfalls
: Zurich’s town

Train route: 31h



: Observation platform of Gornergrat
: Chillon’s castle
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: Lugano’s town
: Berne’s town
: Lucerne’s town
: Rhin’s waterfalls
: Zurich’s town

Conclusion:
The journey by train is more than twice as long as by car. A traveler who wants to minimize his total travel time would therefore be well advised to choose the car as a mean of transport, as this would save him 16 hours and 20 minutes. But don’t forget that depending on the number of passengers, a train can be up to 10 times more ecological than a car for the same distance travelled...

We have chosen not to present graphically the optimal routes according to distance and costs. Indeed, their visualization is not relevant, the path concerning the distance would imply to trace the Swiss road/rail network and we do not have access to these data in a precise way, moreover it would be much more difficult to observe graphically than for the time. Regarding the costs, these are directly related to the distance for the car and the train and are therefore not more representative than the optimal route versus distance. However, these two algorithms give us extremely interesting information on which we can conclude in writing.

The optimal path obtained with the TSP algorithm over distance gives us 1023km by car and 1218km by train. Travelling by car is way shorter, more practical and has surely more advantages. But by comparing the CO_2 emissions of both transportations’ mode, it's clear that train is much more ecological. In fact, given that a train journey on average 37g of CO_2 per kilometer, this journey represents an impact of 45.066kg of CO_2 but for a whole train! Even with only one wagon, this is significantly less than a car which emits on average 121g of CO_2 per kilometer, her journey represents an impact of 123.783kg of CO_2. Without considering that a train carries much more traffic than a car, it is already more than 3 times more ecological to use the train to visit Switzerland. Depending on consumers preferences and way of consuming, this analysis can provide him different information about his emissions and the distance he must travel to make the whole tour and thus to make its choices of voyage in function.

Using our distance matrix and our first algorithm, we have calculated the optimal (minimum) distance to visit the 10 destinations. We can now calculate the cost of visiting these 10 destinations by car.
Considering that petrol has an average price of 1.8CHF and that an average car consumes about 7 liters of petrol per 100km, we arrive at a total price of 128.9 CHF which does not include the price of the car rental which is estimated to be about 65 CHF per day nor the prices of the visits.
As far as the train is concerned, we have considered in our working matrix the prices of the half-fare tickets provided by the SBB. After optimizing this matrix with the TSP, we obtain a minimum price of CHF 279.5 to visit all 10 destinations with half-fare tickets.
To access such prices, a 185 CHF card needs to be ordered. Therefore, it would cost 459.5 CHF in total. It stays cheaper than travelling with full-fare tickets which would have cost 559 CHF.

To conclude about costs, we can see that the train is still extremely expensive to travel on. However, for family travel, children under 16 years of age benefit from a preferential rate of CHF 19 per day. This reduces the cost of tickets for a whole family.

Through Packing Problem & Knapsack algorithms, we will now try to arrive at more precise results to provide more accurate conclusions as well as suggestions of behavior in terms of means of transport for each type of customer according to their budget, their ecological awareness, and their interest in the different tourist attractions.

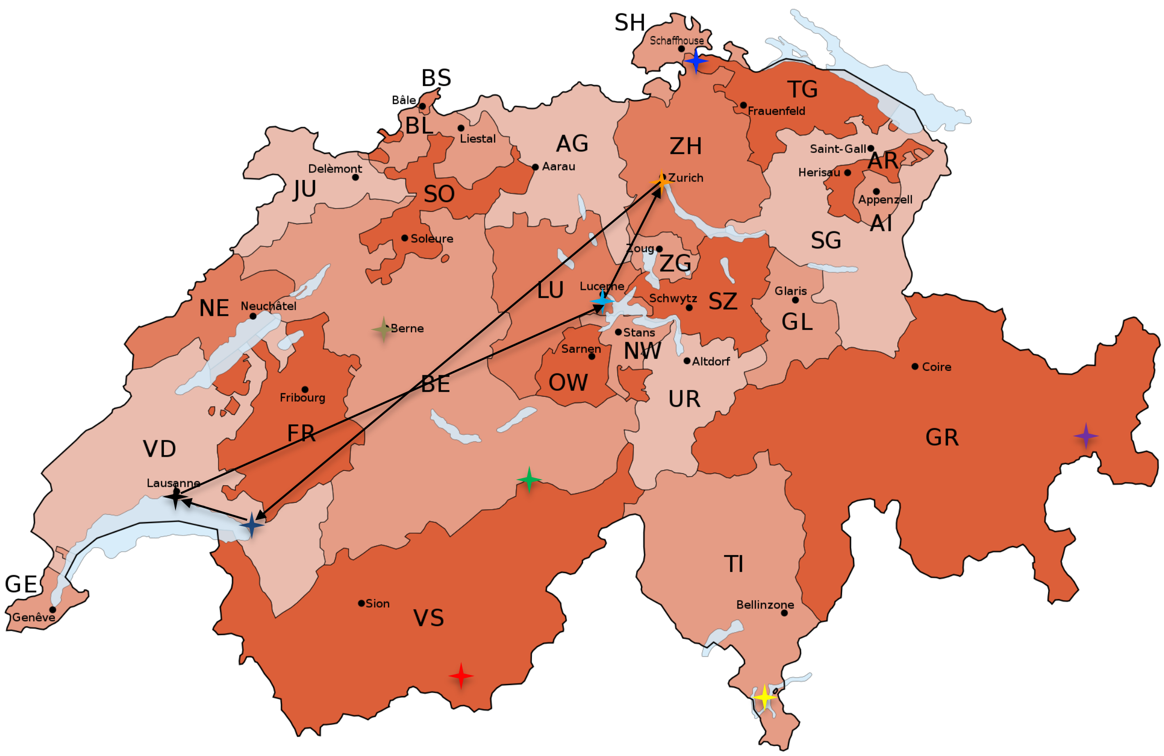
5.2 Packing problem: Finding the best route with given time constraint

For this analysis we have re-used the travel time matrix by **car**. In addition to this we have taken into account, the visiting times, the TripAdvisor ratings of the tourist sites and we give the user the possibility to give us the interest he has in the rating of the tourist sites he is going to visit, the number of days available for his trip, the time he wants to allocate to daily visits and the point of departure which is again by default set at Zurich which is the main Swiss airport (it can be modified by changing the index attributed to the starting_point variable).

We will build up typical traveler and holiday profiles and use the algorithm to see what our recommendations might be to these different types of travelers.

Profile 1: Weekend (48h) for a couple, 6 hours of visiting per day, gives a high value on quality of visit (10/10 scale)

Car route: 11h30



: Observation platform of Gornergrat
: Chillon's castle
: Jungfraujoch
: Schweizerischer national park
: Lemanic Lake in Lausanne
⇒ *Selected destination*

: Lugano's town
: Berne's town
: Lucerne's town
: Rhin's waterfalls
: Zurich's town

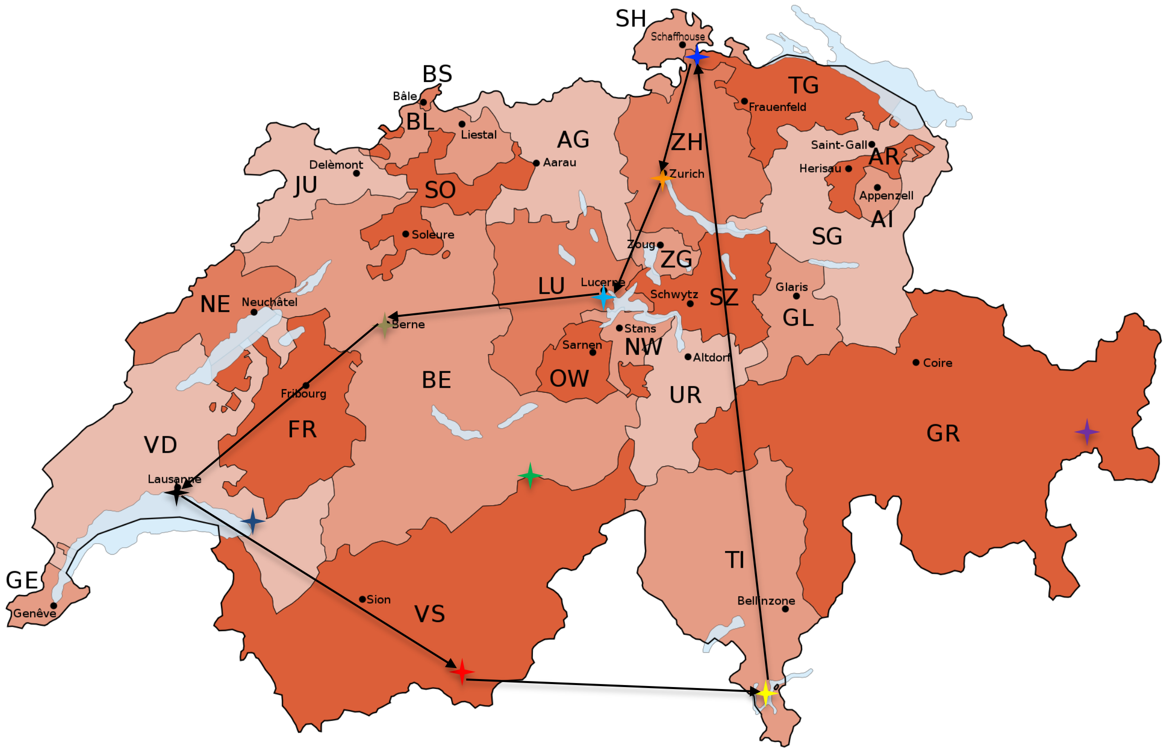
Algorithm output:
Optimal route: Zurich ⇒ Chillon's castle ⇒ Lemanic Lake in Lausanne ⇒ Lucerne ⇒ Zurich
With your actual constraints, you are visiting: 4 places of the top 10 destinations in Switzerland.
This itinerary is based on an attraction weight coefficient of 10/10
Total time spent on travelling: 11.5 hours.
Remaining time on the last day: 5 hours, 30 minutes.

Such a travel would cost:
By car:
⇒ Gas: (207+76+154+51)/100*7*1.8 = 61.49 CHF
⇒ Car rental: 65*7 = 130 CHF
Total: **191.49 CHF**

Again, it's possible to change the matrix for the train travel times but it depends on traveler's preferences. The choice of transport will therefore depend on the traveler's interest in their environmental footprint and the dedicated budget to their travel (because train is likely more expensive).
⇒ This price does not consider the cost of accommodation and food as well as expenses for local visits.

Profile 2: Holiday week for a family (4 people), 3 hours of visiting per day, gives a middle value on quality of visit (4/9 scale).

Car route: 20h40



: Observation platform of Gornergrat
: Chillon's castle
: Jungfraujoch
: Schweizerischer national park
: Lemanic Lake in Lausanne
⇒ *Selected destination*

: Lugano's town
: Berne's town
: Lucerne's town
: Rhin's waterfalls
: Zurich's town

<u>Algorithm output:</u>
Optimal route: Zurich ⇒ Lucerne ⇒ Berne ⇒ Lemanic Lake in Lausanne ⇒ Observation platform of Gornergrat ⇒ Lugano ⇒ Rhin's waterfalls ⇒ Zurich
With your actual constraints, you are visiting: 7 places of the top 10 destinations in Switzerland.
This itinerary is based on an attraction weight coefficient of 5/10
Total time spent on travelling: 20.6666668 hours.
Remaining time on the last day: 2 hours, 40 minutes.

<u>Such a travel would cost:</u>
By car:
⇒ Gas: (51+44+76+236+251+220+53)/100*7*1.8 = 117.31 CHF
⇒ Car rental: 65*7 = 455 CHF
Total: **572.31 CHF**

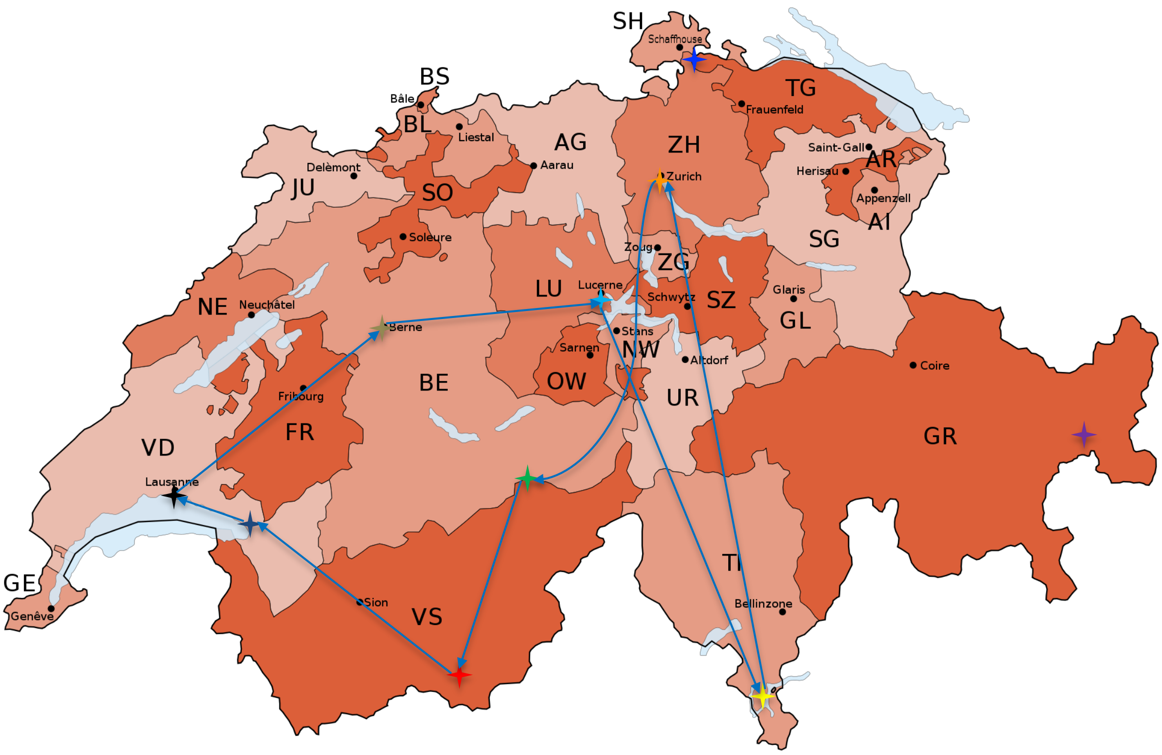
Again, it's possible to change the matrix for the train travel times but it depends on traveler's preferences. The choice of transport will therefore depend on the traveler's interest in their environmental footprint and the dedicated budget to their travel (because train is likely more expensive).
⇒ This price does not consider the cost of accommodation and food as well as expenses for local visits.

5.3 Packing problem: Finding the best route with given budget constraint

For this analysis we have re-used the travel cost matrix by **train**. As we will discuss in the conclusion, the train has many advantages over the car apart from the price. We will come back to this choice later. In addition to this we have considered, the visiting costs, the TripAdvisor ratings of the tourist sites and we give the user the possibility to give us the interest he has in the rating of the tourist sites he is going to visit, the available budget for his trip, if he wants to take the half-fare card (185 CHF in his budget) and the point of departure which is again by default set at Zurich which is the main Swiss airport (it can be modified by changing the index attributed to the starting_point variable).

Profile 1: Couple with a high budget of 400 CHF/person for their trip, gives a high value on quality of visit (10/10 scale) and take the half-fare card.

Train route: 398.38 CHF/person →



: Observation platform of Gornergrat
: Chillon's castle
: Jungfraujoch
: Schweizerischer national park
: Lemanic Lake in Lausanne
⇒ *Selected destination*

: Lugano's town
: Berne's town
: Lucerne's town
: Rhin's waterfalls
: Zurich's town

Algorithm output:

The optimal route according to your budget is: Zurich ⇒ Jungfraujoch ⇒ Observation platform of Gornergrat ⇒ Chillon's castle ⇒ Lemanic Lake in Lausanne ⇒ Berne ⇒ Lucerne ⇒ Lugano ⇒ Zurich and is based on an attraction weight coeff. of 10 on a scale of 10.

With your 400.0 CHF personal budget, you can thus visit 8 different destinations.

Total cost of the trip is: 213.38 CHF + the price to have access to the half-fare which gives a total of: 398.38 CHF

Remaining personal budget after the trip: 1.62 CHF

⇒ In this case, it's relevant for the user to take the half-fare card because 213.38 > 185CHF, if it wasn't the case, the half-fare price would have no interest since paying full price would possibly allow to visit more things (in that case the half-fare price is taking a too big part of the budget). If the user had not taken the card, in this case the program would have suggested him to take it.

Such a travel would thus cost:

By train:

398.38*2 =

Total: **796.76 CHF**

⇒ This price does not consider the cost of accommodations and food as well as expenses for local visits.

Such a travel would take:

By train:

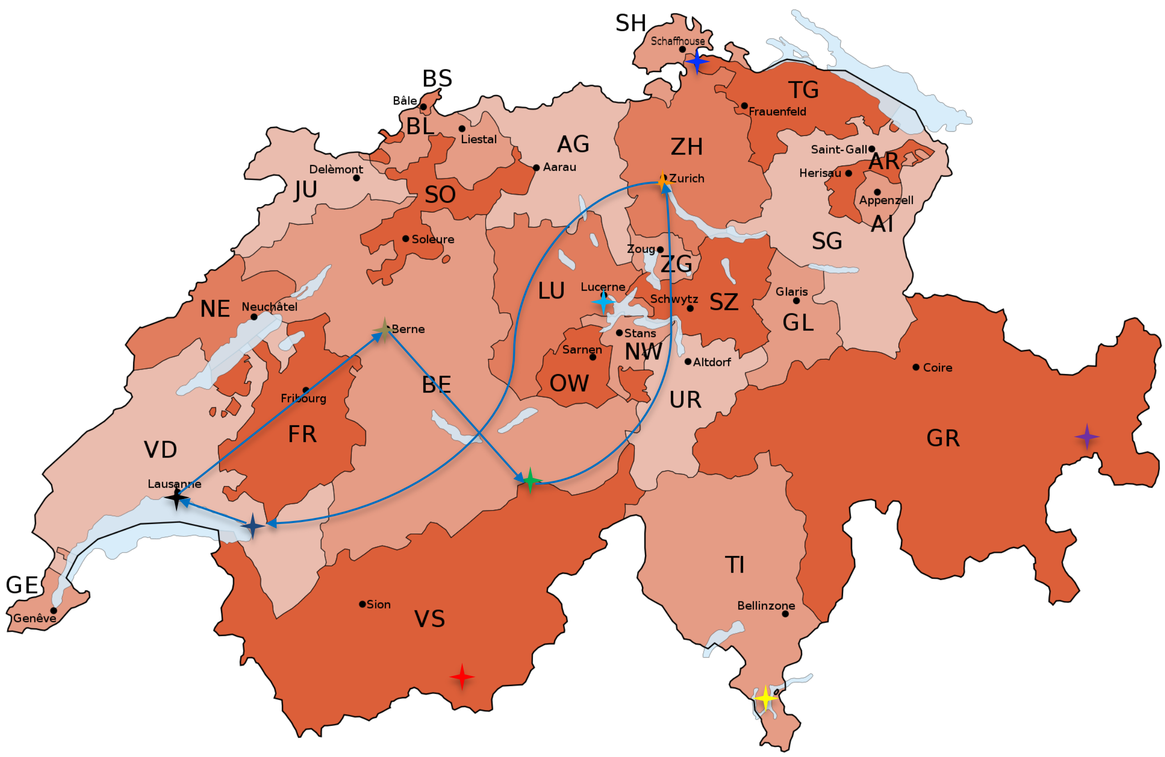
150+180+210+90+60+90+330+150 = 1260 minutes = **21 hours** of travel

We will also need to add the visiting times + the total time of the travel will also depend on the amount of time travelers spend visiting each day.

Again, it's possible to change the matrix for the car travelling costs but it depends on traveler's preferences. The choice of transport will therefore depend on the traveler's interest in their environmental footprint and the dedicated budget to their travel (because train is likely more expensive). In our case, we assumed that traveler or traveling by train for two reasons. First, we can show our adaptation capacity to different data and price variation (with the half-fare) which isn't the case with cars. Secondly, we encourage tourists to use the train during their travel, it's the best way to preserve the Swiss environment but also to discover the country. Swiss trains are renowned worldwide for their quality (comfort, cleanliness, …) but also for the landscapes and views offered on board. Depending on the number of passengers, a train can be up to 10 times more ecological than a car for the same distance travelled...

Profile 2: Family (2 adults + 2 kids) with a middle budget of 300 CHF/person for the adults for their trip, gives a middle value on quality of visit (5/10 scale) and takes the half-fare card.

Train route: 290.03 CHF/adult



: Observation platform of Gornergrat
: Chillon's castle
: Jungfraujoch
: Schweizerischer national park
: Lemanic Lake in Lausanne
⇒ *Selected destination*

: Lugano's town
: Berne's town
: Lucerne's town
: Rhin's waterfalls
: Zurich's town

<u>Algorithm output:</u>

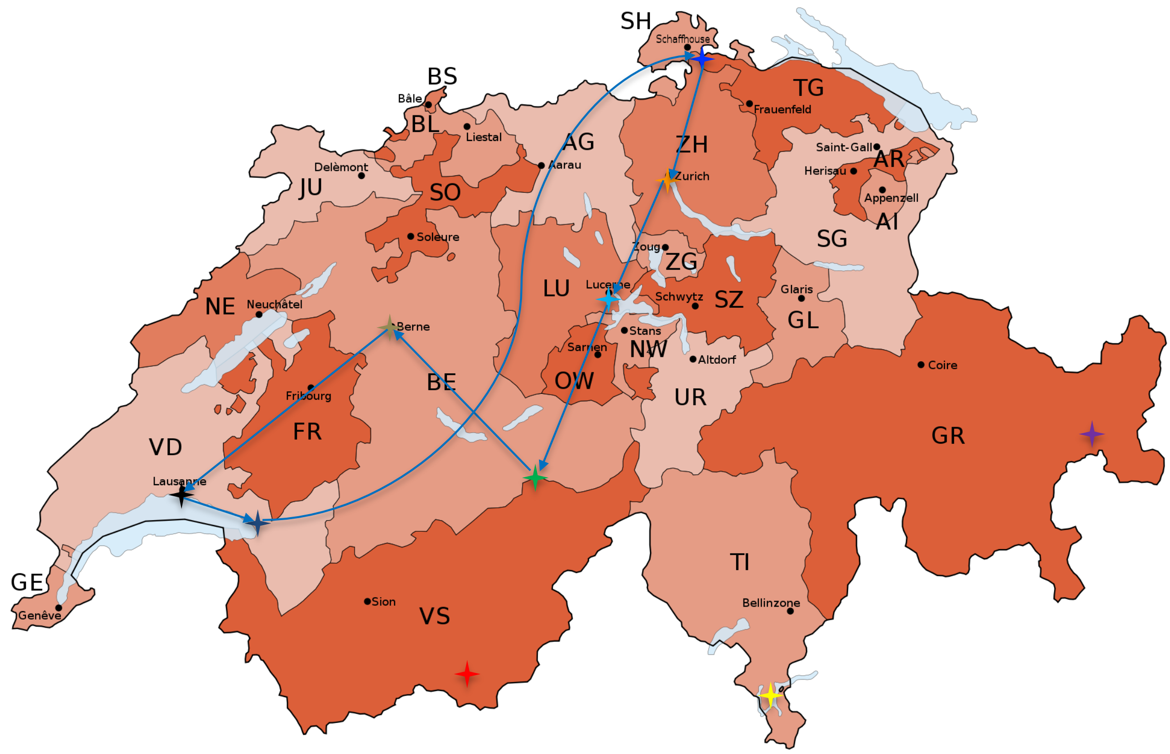
The optimal route according to your budget is: Zurich ⇒ Chillon's castle ⇒ Lemanic Lake in Lausanne ⇒ Berne ⇒ Jungfraujoch ⇒ Zurich and is based on an attraction weight coeff. of 5 on a scale of 10.
With your 300.0 CHF personal budget, you can thus visit 5 different destinations.
Total cost of the trip is: 105.03 CHF + the price to have access to the half-fare which gives a total of: 290.03 CHF
Remaining personal budget after the trip: 1.62 CHF
Since the cost of your trip is: 105.03 CHF which is < 185 CHF, we suggest you not to buy the half-fare card, you will then probably be able to make a bigger travel.

⇒ As explained, the code is here suggesting to possibly improve the total amount of visited destinations to optimize customers experience as much as possible for his budget. Let's then re-run the model without taking the half-fare card.

Profile 2bis: Family (2 adults + 2 kids) with a middle budget of 300 CHF/person for the adults for their trip, gives a middle value on quality of visit (5/10 scale) without the half-fare card.

⇒ Without surprise, the available budget seems to be more optimized than before, let's discover this.

Train route: 298.36 CHF/adult



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: Lemanic Lake in Lausanne
⇒ *Selected destination*

: Lugano's town
: Berne's town
: Lucerne's town
: Rhin's waterfalls
: Zurich's town

<u>Algorithm output:</u>
The optimal route according to your budget is: Zurich ⇒ Lucerne ⇒ Jungfraujoch ⇒ Berne ⇒ Lemanic Lake in Lausanne ⇒ Chillon's Castle ⇒ Rhin's waterfalls ⇒ Zurich and is based on an attraction weight coeff. of 5 on a scale of 10.
With your 300.0 CHF personal budget, you can thus visit 7 different destinations.
Total cost of the trip is: 298.36 CHF.
Remaining personal budget after the trip: 1.64 CHF.

⇒ Here we have no suggestive message from the algorithm, it's thus the best possible route according to the given budget. And in fact, we are visiting two more destinations as in the previous case with the same budget.

Such a travel would thus cost:

By train:

⇒ Adults: 298.36*2 = 596.74 CHF

⇒ Kids: 2*19*X with X the number of days they decide to spend for their travel

Total: **596.74 + 38X CHF**

⇒ This price does not consider the cost of accommodations and food as well as expenses for local visits.

Such a travel would take:

By train:

30+210+150+60+90+270+150 = 960 minutes = **16 hours** of travel

We will also need to add the visiting times + the total time of the travel will also depend on the amount of time travelers spend visiting each day.

Again, it's possible to adapt the code to travel by car but it depends on traveler's preferences. The choice of transport will therefore depend on the traveler's interest in their environmental footprint and the dedicated budget to their travel (because train is likely more expensive).

In our case, we assumed that traveler or traveling by train for two reasons. First, we can show our adaptation capacity to different data and price variation (with the half-fare) which isn't the case with cars. Secondly, we encourage tourists to use the train during their travel, it's the best way to preserve the Swiss environment but also to discover the country. Swiss trains are renowned worldwide for their quality (comfort, cleanliness, …) but also for the landscapes and views offered on board. Depending on the number of passengers, a train can be up to 10 times more ecological than a car for the same distance travelled...

6. Sensitivity analysis

Reminder: Sensitivity analysis is a method to understand how different values of an independent variable impact a particular dependent variable under a given set of assumptions. We are going to perform this analysis on our last model which is, according to us, the most efficient one. In our case, the dependent variable is the best route and score for the tour, which are determined by multiple parameters.

6.1 available_budget

This parameter could significantly impact the optimal itinerary as the higher the budget, the more destinations can be included. We have already observed this phenomenon according to the different profiles we have established in our previous analysis.
All other parameters remaining the same (attraction_weight = 5), here is the impact of changing the budget by 50 CHF:

	Personal budget (CHF)	Visited Destinations	#Destinations Δ (%)
Model 1	150	3	
Model 2	200	4	+33%
Model 3	250	6	+50%
Model 4	300	7	+16.7%
Model 5	350	7	+0%
Model 6	400	8	+14.3%
Model 7	450	9	+12.5%
Model 8	500	10	+11.1%

Obviously, as the available budget increases, the number of destinations visited in the best itinerary increases. We also observe that the marginal variation is smaller and smaller, i.e., the bigger the budget, the fewer destinations are added by adding more budget. We also observe a zero variation for the 350 CHF budget. This is the probably the point at which it becomes worthwhile for the user to buy the SBB Half-Fare Card, we will try to confirm this in the following steps.

6.2 fare

It is interesting to look at the variations in the budget share consumed when using the Half-Fare card or not, as this could potentially tell us more about the possibility of using more of one's budget or not and about the improving of total visited destinations.
All other parameters remaining the same (except budget, starting at 200 because card price is 185 CHF), here is the impact of taking the card or not:

	Personal budget (CHF)	Amount left (without h-f)	#Visited destinations (without h-f)	Amount left (with half-fare)	#Visited destinations (with h-f)	Δ #destinations with h-f (%)
Model 1	200	34.4	4	NA	0	NA
Model 2	250	7.14	6	13	2	-66%
Model 3	300	9.97	5	1.64	7	+40%
Model 4	350	0.04	7	5.17	7	+0%
Model 5	400	21.84	8	1.62	8	+0%
Model 6	450	10.24	8	1.53	9	+12.5%
Model 7	500	2.06	9	7.48	10	+11.1%

We can make several observations about the results obtained above. First, we note that minimizing the remaining budget is not synonymous with optimality in terms of destinations travelled, which is why we have added a message that is displayed in the console depending on the user's request, suggesting whether to take the half-fare card but also to choose the cheapest option in the case where the two options give a similar number of destinations in the optimal itinerary.
Furthermore, we confirm our hypothesis that above a certain amount (between 350 and 400 CHF) taking the half-fare card systematically proves to be the best option to maximize the number of destinations visited by the user.

6.3. Other variables

The sensitivity of our other parameters is managed within the code, as for the attraction_weight variable which is already based on a certain predefined scale. It could also have been relevant to analyze the sensitivity with respect to the cost of visits, but this would not be general as these prices change directly from the moment the list of destinations is changed.

7. Conclusion, managerial insights & recommendations

The initial goal of our project was to create different algorithms with the aim of optimizing tourists' stays in Switzerland in a general way. Thanks to the use of the different tools acquired during the course, we were able to first make rather general analyses before creating algorithms more oriented towards our problem as such.
Several things emerged from this analysis.
First, given the complexity of the cost calculation, there must be a large majority of tourists who travel without optimizing their costs, which does not improve the Swiss problem of travel: the price. We are therefore satisfied with our analysis at this level, which could be transformed and used as a general cost optimization tool for tourists in Switzerland.

Furthermore, we discovered during this analysis that the prices for travelling by train clearly do not encourage travelers to favor this option, which is the best from an environmental point of view, and not only. Apart from the fact that trains are much more environmentally friendly than cars and that their use contributes greatly to the reduction of the country's CO_2 emissions, Swiss trains are world-renowned for their quality (as we have already mentioned) and for the breathtaking scenery that can be seen on board. What better way for tourists to experience more of the country than by taking advantage of their journeys? All in a comfortable and clean environment. Depending on the number of passengers, a train can be up to 10 times more ecological than a car for the same distance travelled...

It is this last observation that leads to our managerial recommendations, which are therefore addressed to SBB. Indeed, the Swiss railway company does not currently offer any preferential tariffs for shorter journeys, except for those under 16 years of age (who, it should be noted, rarely travel alone). From a certain point onwards, our algorithm shows that it is worthwhile subscribing to the annual half-fare card, even for a one-week journey...

Recommendations to the SBB:
- Creation of a reduced fare card for adults, reserved for tourists (whether weekly, daily, ...)
- If such a card does not meet the company's financial objectives, approach the government, which is constantly acting against pollution, to obtain help in creating this process.

Recommendations to tourists, applicable to a travel agency / route creation tool
- For short stays, renting a car remains the cheapest and most convenient option (faster than the train). But don't forget the ecological aspect and reduce your travel time/distance as much as possible.
- Travelling by train can be more expensive but is still affordable for families with young children (-16 years) who pay only 19 CHF per day for train travel. In addition, you will enjoy the additional scenery and comfort of Swiss trains. All this while doing something for the environment and emitting much less CO_2 than if you were to travel by car, thus helping to protect the environment.
Depending on the number of passengers, a train can be up to 10 times more ecological than a car for the same distance travelled...
- A route creation tool may be implemented for the tourists in order to optimize their trip in the way they want to.

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