

A location-allocation model for the hotel selection problem: a case study considering a travel along Japan with the Japan Rail Pass

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ABSTRACT

In addition to the attractiveness due to the mix between history and modernity, the robust Japanese transport infrastructure permits a diverse and comprehensive travel along all country. In this context, the Japan Rail Pass arises as an important ally, as it permits the unlimited travel on all JR (Japan Railways) lines during a determined period. The objective of this work is to determine where to book hotels, making possible the visit by train to all main cities of Japan within a maximum travel time. We propose two mixed-integer linear programming models, solved using the Gurobi solver, in a framework constructed in Python. In experiments, we compare different maximum travel times, maximum number of hotels and flexibility of departure time. The results of our work are, besides the framework itself, an analysis of places to book a hotel in Japan, considering different personal conditions.

KEYWORDS. Hotel selection problem. Location-allocation problem. Japan Rail Pass.

OA – Other applications in Operations Research. PM – Mathematical programming.

1. Introduction

Japan has gained attention as a growing touristic destination. From 2000 to 2019, the number of visitor arrivals increased from 4,757,146 to 31,882,049 people [JNTO, 2021a]. The two main prominent destinations are the Kansai region, on the west, and the Kanto region on the east portion of the country. Precisely, in Kanto region, Tokyo and Chiba represented in 2019, respectively, 42.4% and 32.3% of total sightseeing and leisure visit rates; and, in Kansai region, Osaka, Kyoto and Nara represented, respectively 43.4%, 32.8% and 14.3% of visits with these characteristics [JNTO, 2021b]. In this sense, the robust transport infrastructure of Japan has an important role, as, although separated by approximately 500 km, a travel between Tokyo and Osaka can be performed in 2 hours 30 minutes using the Shinkansen, the Japan's high-speed railway.

For this reason, the use of the Japan rail pass gains importance on touristic travels around Japan. With this pass, temporary visitors for sightseeing can travel unlimitedly on lines of the JR group, during a limited period of 7, 14 or 21 days. This pass permits the use of Shinkansen train, which are the Japan's high speed railway network; JR local trains, which stop on all stations; and JR limited express trains, which perform regional travels through long distances stopping in less stations, but sharing the same rail network of local trains, important especially in regions without Shinkansen lines.

Indeed, due to the comprehensive railway network covered by the Japan Rail Pass, it is possible to reach almost all most famous touristic spots of the country. JR lines comprehend, according to 2018 data, 20,127.1 km of the total 27,606.7 km total Japan railway network, i.e. 73% of the total [MLIT, 2021a]. This represents 4474 train stations [MLIT, 2021b], covering 46 of the 47 Japan prefectures, with exception only of Okinawa, which, being a distant island separated from rest of Japan, is only accessible by air and water transportation. In this sense, the Japan Rail Pass arises as a mean of visiting not only Kansai and Kanto regions, but potentially the whole Japan.

Following these ideas, the main objective of this work is to present a methodology to define the places to book a hotel in Japan, in such way that 1-day round trips to the most important cities of Japan are possible through trains within a maximum travel time, following Japan rail pass rules. The main contributions of this work are, beside the model itself, an analysis of the best places to book a hotel in Japan, considering different personal preferences.

This paper is organized as follows. Section 2 describes the considered problem. Section 3 presents a review of relevant literature. In Section 4, the mathematical modeling of the problem is presented in detail. Section 5 discusses the series of experiments conducted as a case study and its results. Finally, we present our conclusions in Section 6.

2. Problem Definition

Consider a trip to Japan, with different hotels booked, in order to visit a set of determined places. On each day, a different destination is reached from one of these hotels, in round trips, starting at the morning and with return at night to the same hotel. Evidently, in a leisure trip, it is not desirable to waste excessive time during transportation to maximize time on touristic spot, thus all inbound trip should occur within a maximum travel time. Furthermore, excessive hotel changes should be avoided, as displacements with luggage may be difficult or result in extra costs with courier service, thus there should be a maximum number of booked hotels.

Considering this panorama, in this work we propose an allocation-location problem, in which we define the places to stay in Japan, and which destinations are allocated to them, i.e. are visited from them.

We assumed two main interests when planning a trip, which were reflected on objective functions of the proposed models: stay on the places nearer the most famous tourist spots or save

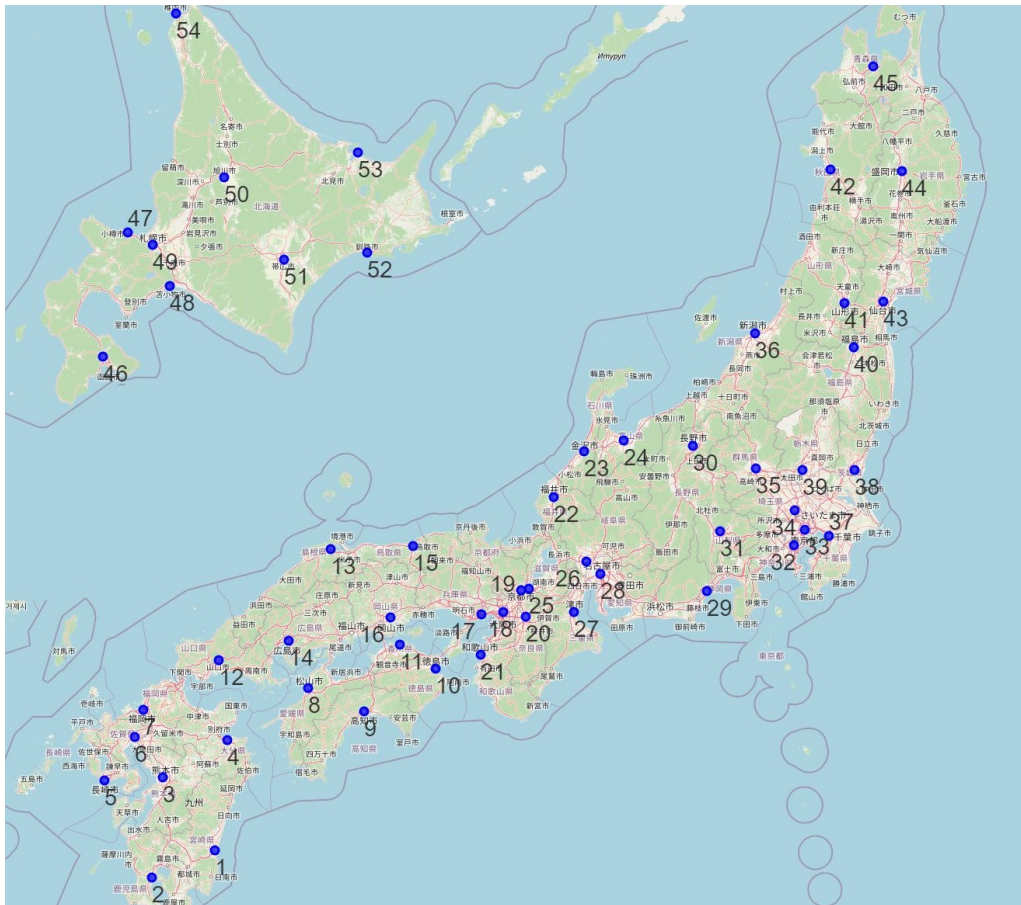


Figure 1: Places to be visited and candidate locations for hotel stay.

money booking the cheapest hotels. In other words, we can minimize total time spent in transportation to reach touristic destinations or minimize total money spent on hotel bookings. These objectives are, usually, conflicting, as well located hotels may have higher booking costs.

In order to make a comprehensive representation of Japan, we considered that both candidate locations for booking a hotel and places that should be visited are the capitals of all 46 prefectures, with exception of Okinawa. Exceptionally, for Hokkaido, the Northernmost prefecture of Japan, there are higher travel times between cities, which is aggravated by its less comprehensive Shinkansen network. All cities considered are on map of Figure 1 and on Table 1.

Following the rules of the Japan Rail Pass, we considered that all transportation shall be performed by trains of the JR group. In this sense, we chose important JR stations to represent the considered cities, as listed in Table 1. This assumption is acceptable as, in Japan, business hotels are usually near the most important train stations. In the same manner, the most representative tourist destinations may be easily accessible from these places.

For each place, we considered a different hotel daily cost, as expressed in Table 1. This is based on the Prefecture's average room rate during 2019's Golden Week – Japan's biggest annual holiday – from 04/29/2019 to 05/06/2019, as released by the Japan's Ministry of Land, Infrastructure and Tourism in MLIT [2019].

ID	City	Representative Station	Hotel daily cost (Yen)	ID	City	Representative Station	Hotel daily cost (Yen)
01	Miyazaki, Miyazaki	Miyazaki	7,573	28	Nagoya, Aichi	Nagoya	8,135
02	Kagoshima, Kagoshima	Kagoshima-chuo	11,886	29	Shizuoka, Shizuoka	Shizuoka	13,398
03	Kumamoto, Kumamoto	Kumamoto	10,900	30	Nagano, Nagano	Nagano	10,581
04	Oita, Oita	Oita	13,479	31	Kofu, Yamanashi	Kofu	11,307
05	Nagasaki, Nagasaki	Nagasaki	15,442	32	Yokohama, kanagawa	Shin-Yokohama	11,507
06	Saga, Saga	Saga	12,814	33	Tokyo, Tokyo	Tokyo	8,092
07	Fukuoka, Fukuoka	Hakata	9,535	34	Saitama, Saitama	Omiya	6,897
08	Matsuyama, Ehime	Matsuyama	11,373	35	Maebashi, Gunma	Maebashi	9,656
09	Kochi, Kochi	Kochi	9,755	36	Niigata, Niigata	Niigata	8,614
10	Tokushima, Tokushima	Tokushima	8,745	37	Chiba, Chiba	Chiba	10,276
11	Takamatsu, Kagawa	Takamatsu	12,268	38	Mito, Ibaraki	Mito	6,798
12	Yamaguchi, Yamaguchi	Yamaguchi	9,864	39	Tochigi, Tochigi	Tochigi	38,390
13	Matsue, Shimane	Matsue	12,166	40	Fukushima, Fukushima	Fukushima	8,570
14	Hiroshima, Hiroshima	Hiroshima	15,811	41	Yamagata, Yamagata	Yamagata	11,070
15	Tottori, Tottori	Tottori	10,431	42	Akita, Akita	Akita	9,444
16	Okayama, Okayama	Okayama	11,284	43	Sendai, Miyagi	Sendai	10,344
17	Kobe, Kobe	Shin-Kobe	11,593	44	Morioka, Iwate	Morioka	10,590
18	Osaka, Osaka	Shin-Osaka	7,792	45	Aomori, Aomori	Aomori	12,930
19	Kyoto, Kyoto	Kyoto	14,018	46	Hakodate, Hokkaido	Shin-Hakodate-Hokuto	10,571
20	Nara, Nara	Nara	14,367	47	Otaru, Hokkaido	Otaru	10,571
21	Wakayama, Wakayama	Wakayama	13,310	48	Tomakomai, Hokkaido	Tomakomai	10,571
22	Fukui, Fukui	Fukui	10,809	49	Sapporo, Hokkaido	Sapporo	10,571
23	Kanazawa, Ishikawa	Kanazawa	15,855	50	Asahikawa, Hokkaido	Asahikawa	10,571
24	Toyama, Toyama	Toyama	10,332	51	Obihiro, Hokkaido	Obihiro	10,571
25	Otsu, Shiga	Otsu	9,917	52	Kushiro, Hokkaido	Kushiro	10,571
26	Gifu, Gifu	Gifu-Hashima	9,678	53	Abashiri, Hokkaido	Abashiri	10,571
27	Tsu, Mie	Tsu	11,943	54	Wakkanai, Hokkaido	Wakkanai	10,571

Table 1: Places to be visited and which are candidates for hotel reservation, with respective average hotel prices.

Travel times between cities were obtained from Navitime [2021], considering the route with earliest arrival, following the Japan Rail Pass rules, i.e. travel only in JR network, with exception of the Nozomi and Mizuho Shinkansen trains. We considered departure on 03/26/2021 for three main reasons: (1) to contemplate the national JR timetable revision which occurred on 03/13/2021 [MLIT, 2021c]; (2) to take into account resumption of normal timetable on Tohoku Shinkansen in 03/26/2021, after special timetable due to an Earthquake occurred in 02/13/2021 [NHK, 2021]; and (3) to consider a weekday timetable.

We considered departures after 8 AM, but, when calculating travel time, we examined two options: a more flexible departure time, in which waiting time at departure station is not accounted; and a more rigid way of travel, in which this time is accounted. This is very important as, in some locations, there are few departures of determined train during a day. For instance, in Wakkanai, the first Limited Express train after 8AM bound for Asahikawa only departs at 13:01.

Obviously, it is very difficult to visit all 54 considered cities on a single trip to Japan. Therefore, we expect that the problem can have a time horizon of several visits to Japan. In this sense, formed clusters of hotels–destinations can help on selecting which places to visit on each travel.

3. Literature review

In some aspects, the studied topic resembles a traveling salesperson problem with hotel selection (TSPHS). In this type of problem, the objective is to provide a route to attend several clients, and decide on which hotels stop along the route, to deal with limitations on the number of places visited on each working day. The term "hotel selection" was introduced on the work of Vansteenwegen et al. [2012], where, beside the modeling itself, the authors presented a solution strategy based on a heuristic with two constructive initialization procedures and improvements with neighborhood search operators.

Subsequently, other authors also studied the same problem, proposing several solution strategies. For instance, Castro et al. [2013] proposed a metaheuristic composed of a memetic

algorithm and an embedded tabu search. Later, Castro et al. [2014] constructed an initial solution through a order-first split-second construction method, and, then, improved solution using an ILS metaheuristic, in which local search is replaced by a variable neighborhood descend (VND). Then, Lu et al. [2017] used the strategy of dynamic programming with a memetic algorithm, and Barbosa e Uchoa [2020] proposed a Branch-Cut-and-Price (BCP) algorithm. Finally, Sousa et al. [2021] suggested, besides an iterated local search heuristic with random variable neighborhood descent procedure, the integration with a data mining technique to construct new solutions.

Specifically, other authors studied a variation named the orienteering problem with hotel selection (OPHS), which is applied specially to problems with touristic purposes, similar to our problem. In this case, there is no need of visiting all points of interest, instead, the objective is to select the places to go, based on a score system, as well as the sequence of visited places and hotels to stop along the route. Several solution strategies were proposed for this problem, such as a modified variable neighborhood search (VNS) [Divsalar et al., 2013]; a memetic algorithm with a genetic component [Divsalar et al., 2014]; a hyperheuristic based on a Large Neighborhood Search [Toledo et al., 2020]; and a Greedy Randomized Adaptive Search Procedure (GRASP) [Sohrabi et al., 2020].

It is important to note that all these works considered that, after the visitation of places of interest, the traveler not necessarily returns to the same hotel, but proceeds to other destinations or hotels. In fact, this may not be applicable to all types of travel, as, for instance, in a train trip, it may be not comfortable to continuously visit several touristic destinations carrying a luggage. Therefore, we propose another view for this type of problem, in which several places are visited from a single hotel, which works as a hub for several 1-day trips. In this sense, the issue can be seen as covering problem, as well as others used for facility location.

This type of problem arises in several fields of research. For instance, determination of the location of fire-station facilities [Badri et al., 1998]; ambulances in tactical level [Gendreau et al., 1997]; base stations for cellular network [Chen e Yuan, 2010]; search and rescue boats [Razi e Karatas, 2016]; bases of emergency services attending a city [Stanimirović et al., 2017], bases of ambulances attending several events inside a city [Ferrari et al., 2018]; bases for ambulances attending road crashes [Mohri e Haghshenas, 2021]; and bases to store oil spill response equipment [Iakovou et al., 1997; Costa et al., 2005; Costa, 2007]. Although the wide range of applications, according to the performed bibliographic research, there is no record of covering models used for problems related to tourism, considering the point of view of the tourist, which highlights the innovation of our work.

With respect to the application to the Japanese panorama, there are indeed some other similar works presenting covering models for the facility location problem applied to the Japan railway network scenario. For instance, Tanaka [2011] proposed a methodology to determine the locations, within 1,393 stations of the Tokyo metropolitan area, where commuters can stop after work to consume some service along a period of time, such as education. The objective was to find the locations which cover the maximum flow of passengers, in such a way that it is possible to arrive at the place after work and proceed to home subsequently, before last train. After, [Tanaka e Furuta, 2013] presented a revision of the same model, considering also the concern of arriving home earlier as possible on weekdays. In this case, experimentation considered the region of Nagoya and surroundings, comprehending 648 stations.

4. Mathematical Models

The problem was modeled as a location-allocation model, in which we define the location of the booked hotels within candidate locations, as well as which places are visited from them.

According to the personal intentions, we considered two main objectives: minimize wasted time on transportation or cost of booked hotels. In this sense, we present two models comprehending each of these objectives, which are explained on Subsections 4.1 and 4.2.

4.1. Time minimization model

The model resembles the proposed by Iakovou et al. [1997], with some simplifications and modifications. Consider the following sets, parameters and decision variables:

Sets:

$i \in \mathcal{I}$	Candidate places to book a hotel
$j \in \mathcal{J}$	Places to be visited

Parameters:

T_{ij}	Travel time between place i and place j
T_{max}	Maximum travel time allowed
N_{max}	Maximum number of hotels to be booked
C_i	Average price per night of hotel in place i

Decision Variables:

$x_{ij} \in \{0, 1\}$	Equal to 1 if the place j is visited from place i
$y_i \in \{0, 1\}$	Equal to 1 if a hotel is booked in place i .

Thus, we have:

$$\min \sum_i \sum_j T_{ij} x_{ij} \quad (1)$$

s.t.

$$T_{ij} x_{ij} \leq T_{max} \quad \forall i \in I, j \in J \quad (2)$$

$$x_{ij} \leq y_i \quad \forall i \in I, j \in J \quad (3)$$

$$\sum_{i \in I} x_{ij} = 1 \quad \forall j \in J \quad (4)$$

$$\sum_{i \in I} y_i \leq N_{max} \quad \forall j \in J \quad (5)$$

$$x_{ij}, y_i \in \{0, 1\} \quad \forall i \in I, j \in J \quad (6)$$

The objective function, 1, minimizes the total inbound travel time between hotels and visited destinations. The constraints 2 imposes that only hotel–destination routes which take less than the maximum travel time are allowed. Constraints 3 ensures that it is only possible to depart from a hotel if this place was booked. Constraints 4 determines that all destinations should be visited one time. Then, constraints 5 limits the number of total booked hotels. Finally, constraints 6 deals with variables domain definition.

4.2. Cost minimization model

Essentially, sets, parameters, decision variables and constraints are the same as the time minimization model. The only change is on the objective function, now represented by equation 7:

$$\min \sum_i \sum_j C_i x_{ij} \quad (7)$$

This new objective function minimizes the total booking costs, assuming that there would be necessary to stay on each hotel the same amount of days as the number of destinations reached from there.

5. Realistic Case Study

A solution framework comprising the mathematical model was implemented in Python with Pulp library and with solution obtained by GUROBI solver. For each of the models, we performed experiments considering several scenarios, comprehending: (i) consider or not waiting time at departure station; (ii) maximum number of hotels between 5 and 15; and (iii) maximum travel time between 30 minutes and 3 hours, in intervals of 30 minutes. Computer had the following configuration: Intel Core I7 2.20 GHz, 16 GB RAM.

Results of experiments are on Tables 3 and 4. On each of the columns, we present optimal solutions for a different scenario, comprehending recommended hotels to be booked – represented by check-marks–, as well as objective function values and computational times for each of the model runs. Note that infeasible scenarios and cities which do not appear on any result are omitted.

Assuming that it shall be better to avoid excessive number of booked hotels, on Figures 2, 3, 4, and 5, we present results concerning the minimal feasible number of hotels for each of the models, considering or not waiting time on departure station. Besides booked hotel locations, we show allocations between hotels and destinations, which can be identified by markers' colors.

	Not considering waiting times at departure station												Considering waiting times at departure station			
Max number hotels	9	10	11	12	12	13	13	14	14	15	15		12	13	14	15
Max allowed travel time(min)	180	180	180	150	180	150	180	150	180	150	180		180	180	180	180
Obj. Funct.(min)	4,372	3,604	3,321	3,238	3,131	2,955	2,955	2,791	2,791	2,641	2,641		4,175	3,741	3,412	3,213
Comp. time(s)	3.9	4.0	3.9	4.0	3.9	4.0	4.0	3.9	4.0	4.0	4.0		3.8	3.8	4.0	4.2
Miyazaki	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Kumamoto																✓
Fukuoka	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
Matsuyama													✓	✓	✓	✓
Takamatsu		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Matsue	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					
Hiroshima																✓
Tottori													✓	✓	✓	✓
Okayama	✓															
Kyoto		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
Kanazawa																
Toyama			✓		✓	✓	✓	✓	✓	✓	✓				✓	✓
Gifu													✓			
Nagoya								✓	✓	✓	✓			✓	✓	✓
Tokyo	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Sendai	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Aomori				✓	✓	✓	✓	✓	✓	✓	✓					
Sapporo	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Kushiro	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Abashiri				✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Wakkanai	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

Table 3: Results of time minimization model.

	Not considering waiting times at departure station												Considering waiting times at departure station			
Max number hotels	9	10	11	12	12	13	13	14	14	15	15		12	13	14	15
Max allowed travel time(min)	180	180	180	150	180	150	180	150	180	150	180		180	180	180	180
Obj. Funct.(Yen)	495, 282	448, 764	443, 686	475, 170	442, 993	463, 706	442, 766	458, 980	442, 766	457, 796	442, 766		497, 389	468, 519	462, 483	460, 709
Comp. time(s)	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.0	4.1	4.1	4.1		4.2	4.2	4.3	4.0
Miyazaki	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Fukuoka	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Matsuyama							✓		✓		✓		✓	✓	✓	✓
Kochi															✓	✓
Tokushima				✓		✓	✓	✓	✓	✓	✓				✓	✓
Takamatsu				✓									✓	✓		
Tottori	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Okayama	✓	✓	✓		✓		✓		✓		✓					
Osaka		✓	✓		✓		✓	✓	✓	✓	✓			✓	✓	✓
Nagoya				✓		✓		✓		✓				✓	✓	✓
Tokyo	✓															
Omiya		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Mito					✓		✓			✓						
Fukushima	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					
Akita												✓				
Sendai								✓		✓			✓	✓	✓	✓
Morioka				✓		✓		✓								
Hakodate											✓					
Otaru				✓		✓	✓	✓	✓	✓	✓					
Tomakomai	✓	✓	✓		✓											
Obihiro				✓		✓		✓		✓			✓	✓	✓	✓
Kushiro	✓	✓	✓		✓		✓		✓		✓					
Abashiri				✓		✓		✓		✓			✓	✓	✓	✓
Wakkanai	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

Table 4: Results of cost minimization model.

There are two types of characteristics that may lead a hotel to be booked: (i) the geographical isolation of the place, which makes some locations reachable only from some places within maximum travel time; and (ii) characteristics authentically related to the objectives of each model, i.e. hotel lower costs or factors that contribute to lower travel time to other destinations, such as proximity to other cities or good transportation network.

Considering the solution in which travel times do not take into account waiting time at departure station, we can divide the cities according to these reasons. In relation to the cities which appear in most of the solutions, some of them were chosen mainly due to the geographic isolation: Miyazaki, Tottori (or Matsue), Kushiro (or Obihiro), and Wakkanai. Others were chosen mainly due to contribution on the minimization of travel times in travel time optimization case, such as: Fukuoka, Takamatsu (or Okayama), Kyoto (or Okayama), Toyama, Tokyo, Sendai, Aomori and Sapporo – note that all places are train hubs, concentrating lines for several destinations. Finally, there were cities which were chosen mainly due to contribution in booking costs in cost optimization case: Fukuoka, Tokushima, Okayama, Osaka, Omiya, Fukushima, and Tomakomai (or Otaru).

In case of considering waiting times at first stations, travel times are longer, making some of the allocations between hotels and destinations infeasible. In some stations, timetables with less

departures can also result in greater waiting times, affecting the solution. In this sense, solutions with this assumption always indicated bookings at Matsuyama and Abashiri, due to isolation of these cities.

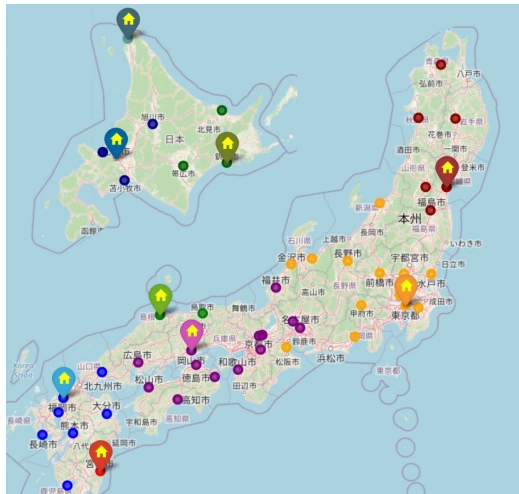


Figure 2: Results for Time optimization model, with 9 booked hotels and maximum travel time of 180h, not considering first station waiting time

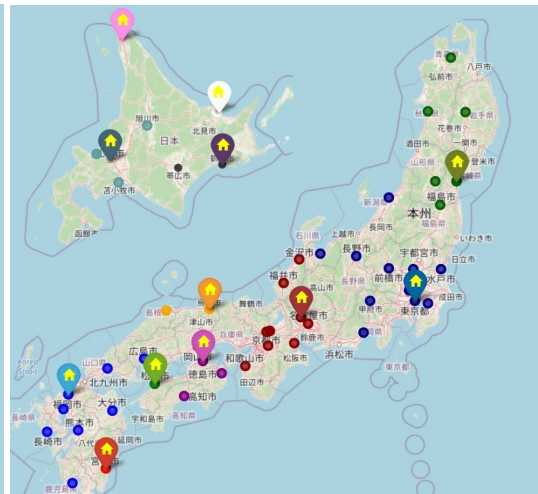


Figure 3: Results for Time optimization model, with 12 booked hotels and maximum travel time of 180h, considering first station waiting time

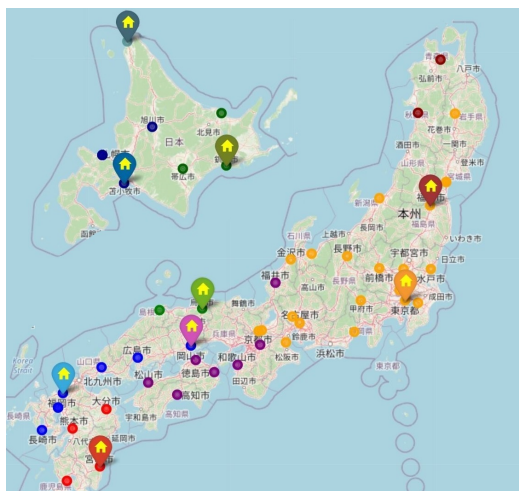


Figure 4: Results for Cost optimization model, with 9 booked hotels and maximum travel time of 180h, not considering first station waiting time

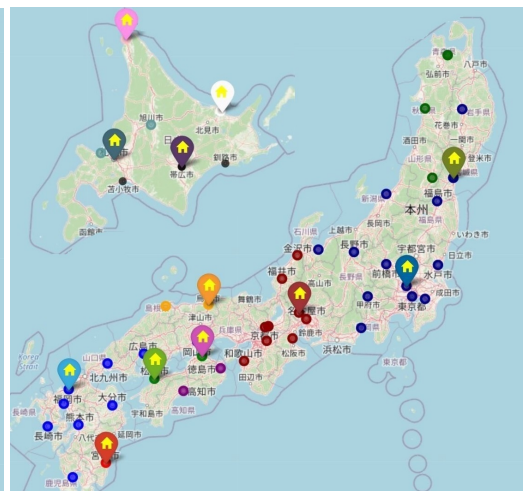


Figure 5: Results for Cost optimization model, with 12 booked hotels and maximum travel time of 180h, considering first station waiting time

6. Conclusion

In this work, we presented a methodology to define, between candidate locations, where to book a hotel, in order to visit a set of places, in 1-day round-trips. We applied this methodology to a study case in Japan, searching the places to stay in such a way that all Japan prefectures, with exception of Okinawa, are possible to be visited by train following the rules of the Japan Rail Pass. Then, we searched for the solutions which minimize hotel booking costs or total travel time.

Several areas can be explored in future works. There may be a better selection of destinations, considering stations near touristic attractions. Contrariwise, the scope may be more comprehensive, aiming a configuration in such a way that all Japan train stations are reached within a maximum travel time. Finally, the model may be mixed with a traveler salesperson model, to define the order of hotel bookings along a travel, allowing visits to touristic destinations between the checkout of a hotel and the next check-in.

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