A Multimodal Traveling Itinerary Problem in a Time Dependent Multimodal Transportation Network for a Fixed Sequence of Nodes with Time Windows

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1. Introduction

With the technological advancements in transportation and rapid growth in human mobility, the transportation modes and services also increased to accommodate passengers. Due to such increase of services and modes, it becomes more difficult to plan a trip especially when it comes to travel multiple cities with waiting time to reach its final destination through a multimodal transportation network.

Multimodal Traveling Itinerary Problem (MTIP) is of significant and fast increasing importance which aims to find the optimal route between the source and destination while using multiple transportation modes. Due to tourism activities around the world, it motivates and justifies initiative that leads to improvements in the sector, particularly of planning a traveling itinerary.

The MTIP is a variant of Traveling Salesman Problem (TSP) which roughly consist of finding minimum distance route that visits exactly one spatially distributed points, and returns to the starting point [1]. Many TSP variants have been reported and studied and mathematical programming models and solution models are often applied to analyze these variants. The variants of TSP especially important to this research are Time Dependent Shortest Path Problem (TDSPP) and Shortest Path Problem with Time Windows (SPPTW) studied in [1][2][3][4]. Several approaches are proposed by authors [5][6][7][8] to address the complex multimodal transportation network and different abstractions are proposed based on graph theory, i.e. hybrid of transfer and relevant graph [8] , transfer graph [6], hierarchical structure network model [9] but none of them proposed for finding the shortest path for a fixed sequence of nodes with time windows. This research work focused on planning traveling itinerary in a Time Dependent Multimodal Transportation Network (TDMTN) for a fixed sequence of nodes with time windows on intermediate nodes.

2. Solution Approach

Given a fixed sequence of nodes $(v_1 \rightarrow v_2 \rightarrow, \ldots.., v_{n-1} \rightarrow v_n)$ where v_1 is the origin node, v_n is the target node and $(v_2, \ldots., v_{n-1})$ are intermediate nodes. Every node is associated with a given waiting time w_i. The objective is to find the shortest path in the directed TDMTN with time windows on each intermediate node. To compute the shortest path between each pair of consecutive node in the sequence of visits for all possible departure and arrival time, a splitting approach is suggested in which each node is split and link into as many sub-nodes as the number of bus stations, train stations and airport in that node. Furthermore these sub-nodes are linked through time-cost dependent links to get a complete directed TDMTN. Hence, the network of given fixed sequence is $G_1 = (V_1, A_1)$. The nodes $v_i \in V_1$ split into n number of sub-nodes (v_{in}). These sub-nodes are linked with its correspondent node v_{i1} with zero-delay cost in such a way that if node is origin in the sequence then (v_i, v_{in}) link is added and if the node is destination in the sequence then a copy (v^*_{in}) of the sub-node is created and added with the link (v^*_{in}, v_i) to the network. Hence G_1 is extended to $G_2 = (V_2, A_2)$ where, $V_2 = \{V_1, v_{in}, v^*_{in}\}$ and $A_2 = \{A_1, (v_i, v_{in}), (v^*_{in}, v_i)\}$.

For a complete directed TDMTN, the time-cost dependent links among the sub-nodes (v_{in}) and (v^*_{jm}) $(i \neq j)$ are added. These links are associated with departure time $(d_{(v_{in},v^*_{jm})})$, arrival time $(a_{(v_{in},v^*_{jm})})$, duration $(\tau_{(v_{in},v^*_{jm})})$ and cost $(c_{(v_{in},v^*_{jm})})$. The edges $A_1 \in G_1$ are removed as it was for creating fixed sequence of path. Hence G_2 is extended to a directed Time Dependent Multimodal Transportation Network $G_3 = (V_3, A_3)$ as shown in Figure 1, where $V_3 = \{V_1, V_2\}$ and $A_3 = \{A_2, (v_{in}, v^*_{jm}) : i \neq j\}$.

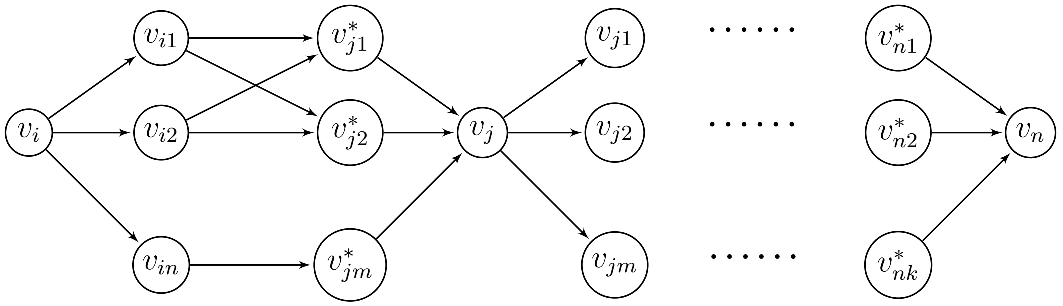

Figure 1: Time Dependent Multimodal Transportation Network

As the directed TDMTN has been created and now to develop a multimodal traveling itinerary in the TDMTN, a Pre-Calculation algorithm were developed which will bound the network within the given Time Horizon of the trip, i.e. Start end (T^s) and End time (T^e) of trip. This will remove the edges among sub-nodes (v_{in}, v^*_{jm}) if $(d_{(v_{in},v^*_{jm})}) < T^s$ and $(a_{(v_{in},v^*_{jm})}) > T^e$. As per preference, the traveler may want to have bounds of arrival or departure time on each edge, i.e. earliest departure (d^e) and latest arrival (a^l) time. Hence, those links will also be removed if departure time among the link is less than (d^e) and arrival time is greater than a^l. After removing all these unwanted edges among sub-nodes, there is a possibility that there maybe some nodes with a degree at most 1, hence we need to remove those nodes also. Hence, in Pre-calculation we remove node if $deg(v) \leq 1$. After the Pre-Calculation Algorithms, Dijkstra Algorithm [x] has modified accordingly and applied to find the minimum cost shortest path in the TDMTN under time constraints.

3. Results and Discussion

A practical example based on real-life flights, trains and buses data for a given sequence of travel $London \to Paris \to Warsaw \to Amsterdam \to London$ has been studied. We collect the data for each city pair in the sequence of travel from online sources (www.ctrip.com) and (www.omio.com). The waiting time at each city in days are London(0), Paris(2), Berlin(3), Warsaw(2) and Amsterdam(2). The time horizon of the trip, (T^s) and (T^e) are $01-04-2019$ $08:00$ and $13-04-2019$ $22:30$ respectively, while d^e and a^l are $8:00$ and $22:30$ respectively. Within the time horizon, considering the average per day connections of flights, buses and trains, there are 102 for $London \to Paris$, 151 for $Paris \to Berlin$, 88 for $Berlin \to Warsaw$, 30 for $Warsaw \to Amsterdam$ and 85 for $Amsterdam \to London$. In total there are

3.4×10^9 potential possible itineraries (including the infeasible). If a traveler tries to plan his/her itinerary in multimodal transportation manually, it would take an unmanageable amount of time. Experiments are performed in Python 3.7.2 on MacBook with Intel Core i5 processor and 16 GB of RAM. The solution approach proposed by us takes 6.82 seconds to develop travelling itinerary. The feasible itinerary developed as shown in Table 1 by our approach under the time constraints to travel in the given fixed sequence cost USD 312 with a total traverse time 33 hours and 45 min.

Table 1: Multimodal Traveling Itinerary

Origin	Destination	Departure Time	Arrival Time	Duration	Mode	Stopover	Transport	Cost (USD)
Victoria Coach Station London	Quai de Bercy, Paris	01-04-2019 10:00	01-04-2019 19:40	08:40	Bus	Direct	Eurolines	22
Charles de Gaulle Airport T2F Paris	Airport Berlin Tegel	03-04-2019 20:45	03-04-2019 22:25	01:40	Flight	Direct	Air France	120
ZOB, Berlin	Dw. Zachodni, Warsaw	06-04-2019 23:40	07-04-2019 08:05	08:25	Bus	Direct	Flix Bus	24
Warsaw Chopin Airport	Schiphol Airport, Amsterdam	09-04-2019 10:00	09-04-2019 14:15	04:15	Flight	1 Stop — CPH	SAS	114
Arena, Amsterdam	Victoria Coach Station	11-04-2019 21:45	12-04-2019 07:30	10:45	Bus	1 Change	Flix Bus	32

4. Conclusion

In this study, we proposed a Multimodal Travelling Itinerary Problem for a fixed sequence of nodes as a variant of traveling salesman problem. MTIP can develop a feasible itinerary for a fixed sequence of nodes at the lowest travel cost. We proposed the splitting of nodes in the sequence into as many sub-nodes as the number of stations in that city and linked them to its nodes. Furthermore, we added time-cost dependent links among the sub-nodes to get a complete directed TDMTN. Furthermore we applied Pre-Calculation algorithm to confined the network according to the user preferences and applied modified Dijkstra Algorithm to find the feasible itinerary. Instead of planning and finding route for each link in each mode of transportation for different time, it will take an unmanageable time for a traveler to plan while our approach take an average of 6.82 seconds to plan the itinerary under the time constraints. In the era of Big data and internet, the study of MTIP can boost the development of tourism industries as it effectively links the gap between travel demand and supply.

In future research, we will consider waiting cost (hotel reservation cost) at intermediate node, combination of different sequence of nodes instead of fixed sequence, and design more detail rules to eliminate more invalid data.

References

[1] A. Arigliano, G. Ghiani, A. Grieco, E. Guerriero, I. Plana, Time-dependent asymmetric traveling salesman problem with time windows: Properties and an exact algorithm, Discrete Applied Mathematics-doi:10.1016/j.dam.2018.09.017.

[2] N. A. El-Sherbeny, The algorithm of the time-dependent shortest path problem with time windows, Applied Mathematics 05 (17) (2014) 2764–2770. doi:10.4236/am.2014.517264.

[3] X. Li, J. Zhou, X. Zhao, Travel itinerary problem, Transportation Research Part B: Methodological 91 (2016) 332–343. doi:10.1016/j.trb.2016.05.013.

[4] W. Jin, S. Chen, H. Jiang, Finding the k shortest paths in a time-schedule network with constraints on arcs, Computers & Operations Research 40 (12) (2013) 2975–2982. doi:10.1016/j.cor.2013.07.005.

[5] M. M. S. Kolyaie, M.R. Delavar, Travel itinerary planning in public transportation network using activity-based modeling, Journal of Applied Sciences 9 (14) (2009) 2532–2543. doi:10.3923/jas.2009.2532.2543.

[6] H. Ayed, D. Khadraoui, Z. Habbas, P. Bouvry, J. F. Merche, Transfer graph approach for multimodal transport problems, in: Communications in Computer and Information Science, Springer Berlin Heidelberg, 2008, pp. 538–547. doi:10.1007/978-3-540-87477-$5_5$7.

[7] O. Dib, M.-A. Manier, A. Caminada, Memetic algorithm for computing shortest paths in multimodal transportation networks, Transportation Research Procedia 10 (2015) 745–755. doi:10.1016/j.trpro.2015.09.028.

[8] H. Ayed, C. Galvez-Fernandez, Z. Habbas, D. Khadraoui, Solving time-dependent multimodal transport problems using a transfer graph model, Computers & Industrial Engineering 61 (2) (2011) 391–401. doi:10.1016/j.cie.2010.05.018.

[9] X. bo Wang, G. jun Zhang, Z. Hong, H. feng Guo, L. Yu, Modeling and implementing research of multimodal transportation network, in: 2009 First International Conference on Information Science and Engineering, IEEE, 2009. doi:10.1109/icise.2009.752.

[10] E. W. Dijkstra, A note on two problems in connexion with graphs, Numerische Mathematik 1 (1) (1959) 269–271. doi:10.1007/bf01386390.