A DISSIMILAR PATHS-SEARCH ALGORITHM FOR EN ROUTE MULTI-ACTIVITIES

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ABSTRACT

With the growing interest in quality-of-life issues, activities en route from an origin to a destination have become more varied and extensive. A driver often performs required or desirable activities on her or his chosen route at various “points of interest” (POIs), such as gas stations, restaurants, department stores, and banks. The driver must decide whether or not to perform an activity at a POI, and, if that decision is positive, he or she must consider multiple information elements to decide where to perform the activity. Two of the most important information elements that must be considered are the relative price of an item at a POI and the additional travel cost (time and money) to get to the POI. The relative price can be defined as the difference between the price at a POI and the minimum price in the network, while the additional travel cost can be defined as the difference between the travel cost to get to the POI and the travel cost associated with the shortest path. This study aims to develop a dissimilar paths-search algorithm for en route multi-activities and verify the efficiency of the algorithm by using a real-world network. The proposed algorithm provides users with multiple alternative paths based on route information and POIs information until users choose their optimal path. To develop the path-search algorithm for en route multi-activities, we used the sum of the relative prices at the POIs and the cost of the route that included the POIs. We considered dissimilarity among alternative paths to provide a variety of information that drivers wish to have. Also, to improve the efficiency of search time, we reconstructed a network based on travel cost constraints and developed a candidate set of alternative paths by executing the shortest-path search algorithm only once. The algorithm developed in this paper was applied to a real network and demonstrated successfully the implementation of the dissimilar paths-search algorithm for en route multi-activities. By comparing the alternative paths that are provided by the algorithm we developed, navigation users can choose the optimal path and decide where to perform they prefer to conduct their activities.

Keywords: points of interest, dissimilar paths, multi-activities, relative price, candidate set

INTRODUCTION

With the growing interest in quality-of-life issues, activities en route from an origin to a destination have become more varied and extensive. A driver often performs required or desirable activities on her or his chosen route at various "points of interest" (POIs), such as gas stations, restaurants, department stores, and banks.

The driver must decide whether or not to perform an activity at a POI, and, if that decision is positive, he or she must consider multiple information elements to decide where to perform the activity. Two of the most important information elements that must be considered are the relative price of an item at a POI and the additional travel cost (time and money) to get to the POI. The relative price can be defined as the difference between the price at a POI and the minimum price in the network, while the additional travel cost can be defined as the difference between the travel cost to get to the POI and the travel cost associated with the shortest path.

On existing route guidance services, users should first select their favorable POIs with location-based services (LBS). Then, they should determine their own route by searching for the shortest path from an origin to each POI and from each POI to a destination, respectively, and connecting these paths. It should be noted that the optimal path does not always pass through a POI with the minimum price. The problem of finding the optimal path that passes through the selected POIs is a complex form of the travelling salesman problem (TSP), which is a non-deterministic polynomial-time hard (NP-hard) problem (Kang, 2008). Therefore, a heuristic algorithm should be used for navigation services since they must quickly provide alternative paths for their users.

This study aims to develop a dissimilar paths-search algorithm for en route multi-activities and verify the efficiency of the algorithm by using a real-world network. The proposed algorithm provides users with multiple alternative paths based on route information and POIs information until users choose their optimal path. In this study, we searched alternative paths by considering the path cost as the sums of the travel cost stemming from a route passing through POIs and the activity costs that are the sums of the purchase and parking costs at POIs.

In the previous literature, parking cost was assumed to be incurred every time any type of activity, such as refuelling, dining, purchasing, and making withdrawals/deposits, is performed at a POI. However, parking fees are incurred only once irrespective of the number of activities performed at the same node (location). In this study, if two or more types of activities are performed at a same node (location), parking cost is calculated based not on the number of types of activities but on the parking cost of the node.

Furthermore, path-search algorithms should provide their users with multiple alternative paths since they may prefer some other attributes, such as familiarity, driving convenience, and fewer right/left turns, over saving a few minutes of driving time (Jeong et al., 2010). We considered dissimilarity among alternative paths to provide a variety of information that drivers wish to have. Also, to improve the efficiency of search time, we reconstructed a network based on travel cost constraints and developed a candidate set of alternative paths by executing the shortest-path search algorithm only once.

A review of previous, pertinent literature is provided in the next section. In addition, we describe the development of the proposed algorithm, including the construction of the set of candidates, the calculation of activity costs, and the calculation of overlap ratios. After that, the new algorithm is tested on a network in Philadelphia, Pennsylvania, USA. Last, our conclusions are presented.

LITERATURE REVIEW

As mentioned above, since the problem of finding the optimal path that passes through selected POIs is an NP-hard problem, solutions presented in the previous literature have usually been based on the use of heuristic algorithms. Oh (2003) selected a set of candidate alternatives using the Euclidian distance between an origin, the destination, and the POIs. Then, he calculated the travel costs associated with the candidate paths that passed through the POIs and selected the optimal path.

Kang (2009) suggested an exact algorithm based on the modified K^{th} shortest path method, the single minimum cost POI method, and Genetic Algorithms. Kang's algorithm uses adaptive dynamic programming with or without multiple alternative solutions and heuristic algorithms. In Kang (2009), the exact algorithm was presented only to find the global solution, because it required too much time to be applied for real navigation services. On the other hand, heuristic algorithms can find alternative paths quickly, but they cannot provide alternative paths that satisfy the user-allowable shared-length ratio. Jeong et al. (2007) suggested a heuristic method that can find multiple alternatives quickly to serve users' various needs, but they did not consider the duplication rates among the alternative paths.

In the previous literature, parking cost was assumed to be incurred every time a type of activity, such as refuelling, dining, purchasing, and making withdrawals/deposits, was performed at a POI. In this study, parking cost is calculated based on the number of nodes (locations) using the method to establish the candidate sets suggested by Jeong et al. (2007) rather than on the number of types of activities.

To date, several studies have been reported that searched multiple paths and considered the duplication rates among the alternative paths. Park et al. (2002) developed an exact approach to search multiple paths considering overlaps and travel costs based on an efficient vector-labelling approach. Jeong et al. (2010) developed a heuristic algorithm that searches multiple, dissimilar paths by using a candidate set, and Lim and Rhee (2010) suggested a heuristic method using penalties for links that were part of a previous path.

When alternative paths are searched considering shared length rates, the smaller the allowable shared length rates, the smaller the number of alternative paths searched. On the other hand, alternative paths that are similar to paths already found in previous searches are frequently provided when shared length rates are not considered. In this study, the path with the minimum average shared length ratio among the paths that have already been searched is selected as an alternative path after establishing the set of candidates considering allowable travel cost and POI information based on the method suggested by Jeong et al. (2010).

ALGORITHM DEVELOPMENT

Establishment of the Set of Candidates

Jeong et al. (2010) established the set of candidates using user-specified allowable travel cost ratio (UATCR) and user-specified allowable shared length ratio (UASLR). The number of alternative paths searched that satisfies these two ratios at the same time is limited. The UATCR can be applied for all candidates as the same value, while the UASLR depends on the paths already found in previous searches. Therefore, in this study, the set of candidates is established considering only the UATCR, and the path with the minimum average shared length ratios with already searched paths is selected as an alternative path among the candidates.

Calculation of Activity Costs

Purchase costs at a POI are incurred every time a type of activity, such as refuelling, dining, purchasing, and making withdrawals/deposits, is performed at a POI. As mentioned above, parking cost is incurred just once regardless of the number of types of activities that are performed at the same node (location).

Activity cost are the sum of the purchase and parking costs at POIs. To minimize activity cost, the set of nodes of the candidate path where items should be purchased can be determined as the following formulation, in which the activity cost of the candidate path is calculated by $\sum_i n_i \sum_j P_{ij} Y_{ij} + \sum_j c_j X_j$.

$$
\begin{aligned}
\text{Min} \quad & \sum_i n_i \sum_j P_{ij} Y_{ij} + \sum_j c_j X_j \\
\text{s.t.} \quad & \sum_j Y_{ij} = 1 && \forall\, i \\
& \sum_j Y_{ij} \le n X_j && \forall\, j \\
& X_j = 0\,,1 && \forall\, j \\
& Y_{ij} = 0\,,1 && \forall\, i, j
\end{aligned}
$$

where
n : is the number of item to be purchased
i : is the item index (1, ..., i , ..., n)
N : is the set of nodes where items are sold on a candidate path
j : is the node index ($j \in N$)
n_i : is the amount of item i to be purchased
P_{ij} : is the relative purchase cost of an item i at node j (∞ if the item i is not sold on node j)
c_j : is parking cost incurred at node j
X_j : is 1 if any item is purchased at node j, 0 otherwise
Y_{ij} : is 1 if an item i is purchased at node j, 0 otherwise

The costs of alternative paths should be lower than an allowable range from the lower limit. The lower limit should be considered as just the sum of the minimum travel cost and the minimum activities costs, and the purchase cost of each path should be calculated as the sum of relative costs from the minimum prices of each item. This is a reasonable approach because the change of the path costs is relatively insensitive to the difference of the purchase cost when higher-priced items are purchased.

Table 1 shows the case in which the lower limit of path costs and the cost of alternative 1 are calculated by using absolute purchasing cost rather than the relative cost. Alternative 1 can be included in the set of candidates since the cost is only 2% larger than the lower limit. However, as shown in Table 2, the cost of alternative 1 is 20% greater than the lower limit if the relative cost is used. In this study, purchase cost is calculated using the relative cost since including absolute purchasing cost can lead to a decrease in the efficiency of the algorithm.

Table 1 – When the activity costs are calculated by using absolute purchasing cost

	Travel cost	Activity cost	Path cost	The path cost ratio of Alt.1 to the lower limit.
The lower limit	10,000	90,000	100,000	-
Alt.1	11,900	90,100	102,000	1.02 (2%)

Table 2 – When the activity costs are calculated by using relative cost

	Travel cost	Activity cost	Path cost	The path cost ratio of Alt.1 to the lower limit.
The lower limit	10,000	0	10,000	-
Alt.1	11,900	100	12,000	1.20 (20%)

Calculation of Shared Length Ratios

In Park et al. (2002) and Lim and Rhee (2010), the shared length ratio was calculated as the ratio of the shared length to the length of the candidate path. This calculation of the shared length ratio, however, may cause the following problem. As shown in Figure 1 and Table 3, for alternative 1, the ratio of the shared length to the shortest path (SP) is calculated as 60%, not 100%, so alternative 1 can be selected as the alternative path in spite of the fact that alternative 2 is also a reasonable alternative path.

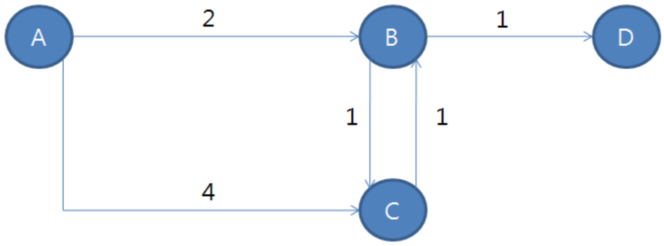

Figure 1 - Toy Network

Table 3 – POI data

	Path	Length	Shared length ratio	
			To the length of the candidate path	To the length of the selected path
SP	A - B – D	3	-	-
Alt.1	A - B - C - B – D	5	3/5 (60%)	3/3 (100%)
Alt.2	A - C - B – D	6	2/6 (33%)	2/3 (67%)

As suggested by Jeong et al. (2010), the shared length ratio of a candidate path in this study is calculated as the ratio of the shared length to the length of the path already found in previous research. The candidate path with the minimum shared length ratio among candidate paths is selected. The next search for alternative paths continues by repeating the process until the user chooses a preferred alternative path.

ALGORITHM IMPLEMENTATION

Data

The algorithm developed in this study was applied to real Philadelphia network data, 'Philadelphia_network.txt', that were downloaded from http://www.bgu.ac.il/~bargera/tntp/. The network consisted of 11,864 nodes and 30,199 links. We used the values of 'length (miles) table' for link length and the values of 'ftime (minutes) table' for link cost. Travel cost was calculated as the sum of time cost and distance cost.

Based on the guideline published by the Korea Development Institute (2003), the value of time was set to 221 Korean won/min, and distance cost was calculated based on a cost of 133.2 Korean won/km. The locations and purchase costs at POIs and parking costs at nodes (locations) were generated randomly. The results are shown in Table 4 and Figure 2. In Figure 2, X-axis means the relative cost and Y-axis means the number of POIs.

Table 4 – POI data

POI	Number of POIs	Price Range	Relative Cost Range
P1	2,000	10,000~20,000	0~10,000
P2	1,000	10,000~16,000	0~6,000
P3	500	26,000~30,000	0~4,000

Figure 2 – Purchase cost distribution

Result

We used C++ for programming the computer and implemented the algorithm using a computer with Pentium Core2 Quad 2.66-GHz processor, a Windows XP operating system, and 2 GB DDR RAM. When the path from node 699 to node 3974 with three POI services was searched, it took 0.219 second to find the shortest path and 5 alternative paths.
The average travel cost of the five alternative paths was 3.19% greater than the travel cost of the shortest path, and the average shared length ratio was 44%. It took slightly more than 531.25 seconds to calculate all 1 x 10^9 cases (2,000×1,000×500 cases) for finding the optimal path.

Table 5 shows the origin nodes, the selected POI nodes, and the destination nodes of each path. Table 6 shows parking costs, purchase costs, and the cost of each path.

Table 5 – Selected locations

	O	P1	P2	P3	D
SP	699	1731	1731	6614	3074
Alt.1	699	612	4394	6614	3074
Alt.2	699	533	1731	6614	3074
Alt.3	699	2005	4394	6614	3074
Alt.4	699	533	1731	6614	3074
Alt.5	699	3119	4394	6614	3074
Optimal	699	533	1731	6614	3074

Table 6 –Parking costs, purchase costs and path cost of each path

	P1		P2		P3		path cost
	Parking	purchase	parking	purchase	parking	purchase	
SP	321	700	-	200	126	400	1,747
Alt.1	112	100	166	700	126	400	1,604
Alt.2	9	100	321	200	126	400	1,156
Alt.3	239	900	166	700	126	400	2,531
Alt.4	9	100	321	200	126	400	1,156
Alt.5	112	1300	166	700	126	400	2,804
Optimal	9	100	321	200	126	400	1,156

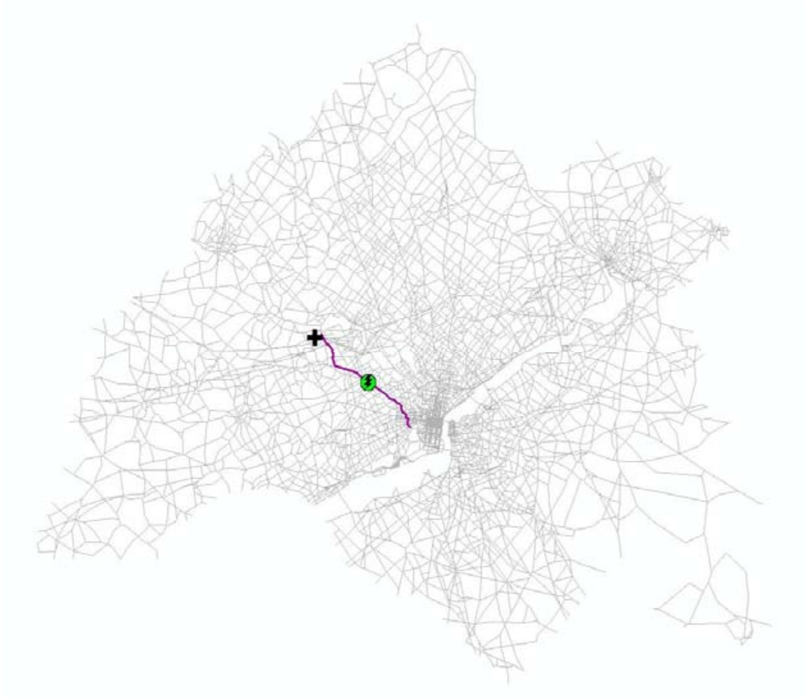

Figure 3 – shortest path

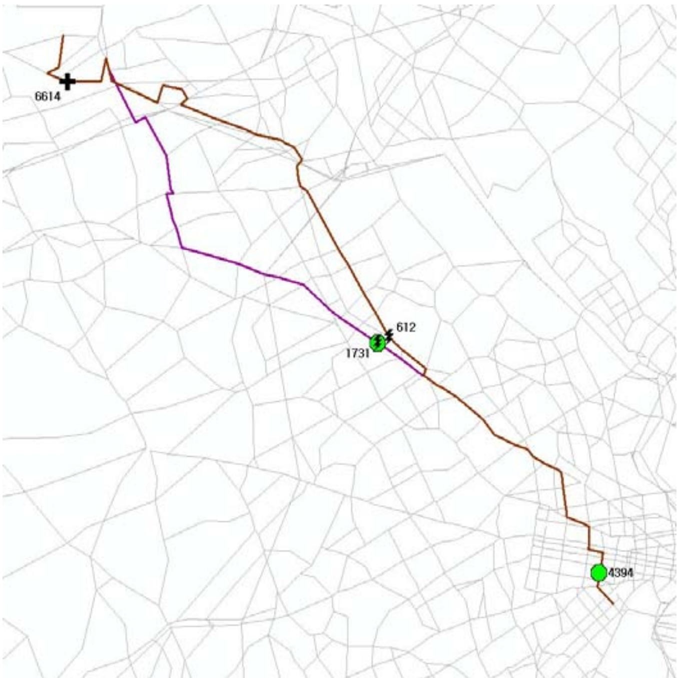

Figure 4 – shortest path and alternative path 1(upside)

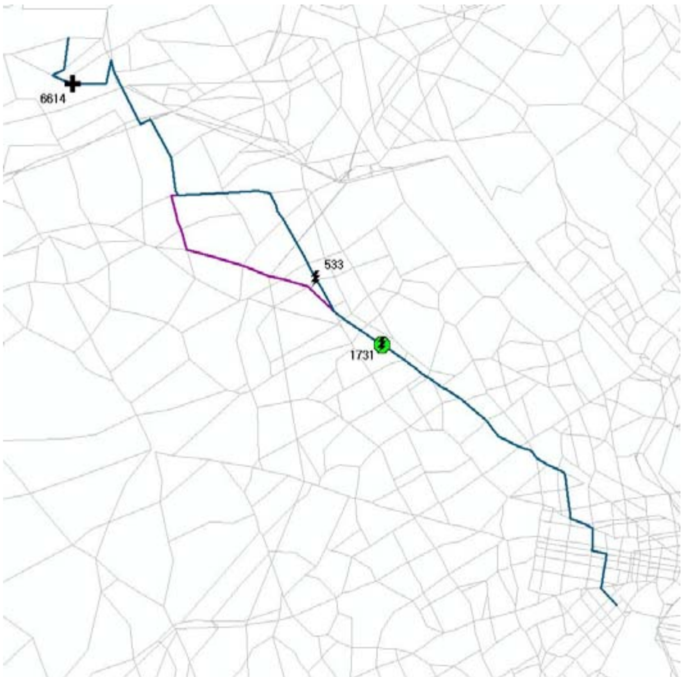

Figure 5 - shortest path and alternative path 2(upside)

Figure 6 - shortest path and alternative path 3(upside)

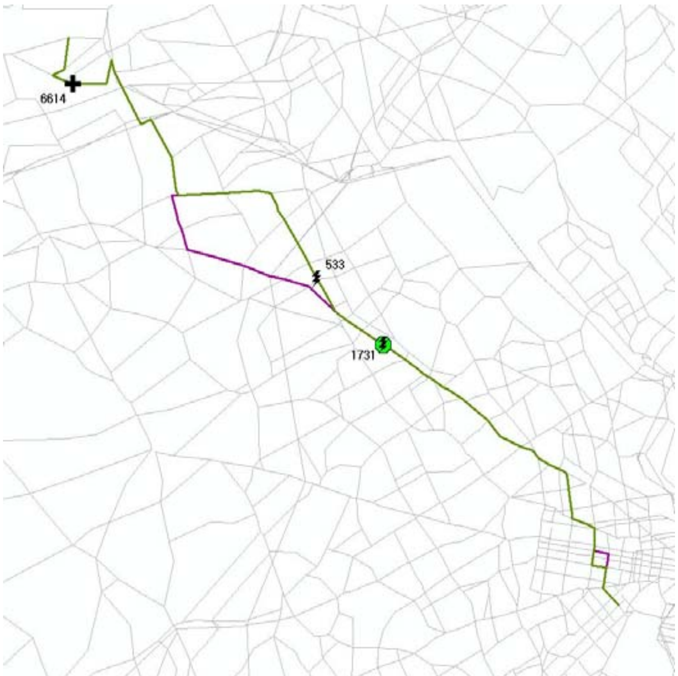

Figure 7 - shortest path and alternative path 4(upside)

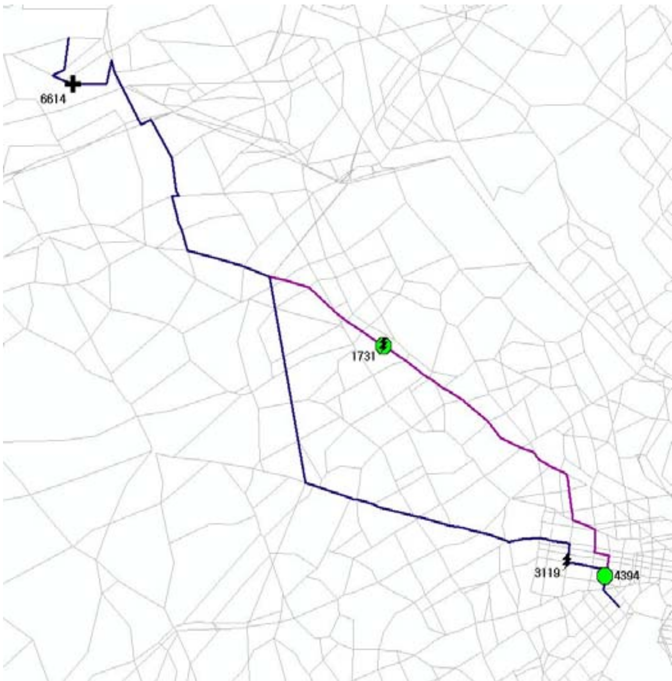

Figure 8- shortest path and alternative path 5(downside)

Table 7 shows the difference between the optimal path and alternative paths. The alternative path 2, 4 and the optimal path is the same cost. The average path cost of the five alternative paths is only 8.33% greater than the cost of the optimal path.

Among these alternative paths, the user who is sensitive to activity costs will select alternative path 2 and 4, while the user who is sensitive to only travel cost will select shortest path. Furthermore, some users will give up the POI service after comparing the travel cost of the shortest path and the path costs of alternative paths including travel cost and activities cost.

Table 7 –The difference between the optimal path and alternative paths

	travel cost	the ratio with minimum travel cost(%)	activities costs	path cost	the ratio with Optimal path cost(%)
SP	11,399	-	1,747	13,146	4.61
Alt.1	11513	1.00	1,604	13,117	4.38
Alt.2	11,410.4	0.1	1,156	12,566.4	0
Alt.3	12,179.8	6.85	2,531	14,710.8	17.06
Alt.4	11,410,4	0.1	1,156	12,566.4	0
Alt.5	12,299.5	7.9	2,804	15,103.5	20.19
Optimal	11,410.4	0.1	1,156	12,566.4	-

CONCLUSIONS

This study developed a dissimilar paths-search algorithm for en route multi-activities to provide users with multiple alternative paths quickly so users can choose their preferred path. To develop the path-search algorithm for en route multi-activities, we used the sum of the relative prices at the POIs and the cost of the route that included the POIs. We considered the dissimilarity among alternative paths to provide the variety of information that drivers wish to have. To improve the efficiency of the search time, we reconstructed the network using a cost constraint and developed a candidate set of alternative paths by executing the shortest-path search algorithm only once. The algorithm developed in this paper was applied to a real network and demonstrated successfully the implementation of the dissimilar paths-search algorithm for en route multi-activities. By comparing the alternative paths that are provided by the algorithm we developed, navigation users can choose the optimal path and decide where to perform they prefer to conduct their activities.

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