Optimal Urban Transportation Network for Tourism via Lane Reservation

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Abstract

In order to improve tourist satisfaction and promote the coordinated development of tourism and urban, this paper investigates an urban transportation network problem for tourism via lane reservation strategy. The focus of the problem is to select some lanes from the existing transportation infrastructure and convert them to reserved lanes for tourism so that tourist satisfaction can be ensured. However, the lane reservation strategy may cause the impact on traffic because of disallowing the use of reserved lanes by general vehicles. Thus, the objective of the paper is to minimize the total impact on traffic of the urban transportation network. In this paper, an integer model is formulated which is different from the existing models on the objective function, the constrain of task and the measure of making reservation lane. The model is proved to be effective and superior by the results shown via Lingo in the example of the tourist urban of Luoyang.

Key words: TOURISM, URBAN TRANSPORTATION NETWORK, OPTIMAL LANE RESERVATION, TOURIST SATISFACTION

1. Introduction

Tourism as an economic activity has become one of the world’s largest industries [1, 2], and already accounted for 266 million jobs and 9.5 per cent of global GDP in 2014. According to the forecast by the World Travel & Tourism council, Travel & Tourism’s global impact on GDP is set to rise by 4 percent per annum over the next 10 years. The transportation system of tourism(TST) is a significant and core component of tourism activity, the base and precondition to the development of tourism, and has exerted a profound effect from ancient times [3].

With the rapid development of tourism, it puts great pressure on TST, especially in the tourist urban (TTU). On the one hand, with an increasing population, the quickening of urbanization and motorization process, the demand for transportation will be greater and greater, especially in city centers where the level of human activities is high [4]; on the other hand, the tourism transportation planning has been marked out in TTU, but the influx of foreign visitors also bring unprecedented difficulties and pressure due to implementation of the golden week holiday system and Tourism Fair [5, 6]. Because of the limited space resource, the large cost and environmental concerns, it is becoming less and less feasible to construct new infrastructures [7] on urban TST (UTST). Consequently, how to search new approaches is very important for efficient utilization of the existing transportation infrastructure, to improve tourist satisfaction and promote the coordinated development of tourism and urban.

Tourist transportation has attracted a large number experts and scholars from all over the world for a long time to study in terms of tourist transportation planning [6, 8, 9], transportation impact on tourism demand [10-12], tourist behavior[13-15], sustainable development [16, 17], etc. There are few quantitative studies about efficient utilization of the existing transportation infrastructure in UTST. Nowadays, due to large influxes of visitors on the golden week holiday and Tourism Fair, a series of measures has been introduced by the government, such as odd-and-even license plate rule and tail number limit line policy etc. As a result, these phenomena does not reduce on the travel time and congestion in some special areas of city, it also causes a greater impact on the life of the residents in the whole city.

In recent years, a traffic management strategy called lane reservation has been widely applied in real life. Lane reservation is proposed to accomplish some special tasks of transportation and reserved for only certain categories of vehicles on the existing transportation infrastructure. Because general-purpose vehicles cannot be used on the reserved lanes, it brings relatively less congestion and less travel time for the special users driving on the lane reservation. For example, these methods are applied around the world such as: the high-occupancy vehicle (HOV) lanes in many cities [18], exclusive bus lanes during some time periods [19], some special events such as evacuation during emergency [20], large-scale sport game [21] and so on. The role of UTST is to achieve the necessary spatial displacement of tourists by connecting various tourist areas in a city. If the traffic management strategy of lane reservation is applied in UTST, travel time will be shortened and visitors'satisfaction will reach very high degree, because of disallowing use of reserved lanes by general vehicles. The shorter the time spent on the road, the higher the customer satisfaction on urban tourism. When we have to choose lanes to transport a given amount of tourist for each task and corresponding source–destination (SD) pair, it can considerably reduce the travel time and greatly expand the region's capacity of accommodating tourists. To complete the tasks, one and only one path are selected to be reserved, differ from the classic minimum-cost commodity flow problem. There are several reasons as follows: First, due to traffic congestion in large cities, if do not take some special measures, it is almost impossible to accomplish its task of traffic transport. Second, if lane is reserved, tourists not only can use it but also and travel faster in this reserved lane since other vehicles can no longer use it. Third, unreserved lanes allows all other vehicles to use, it will be more congested. Hence, the problem becomes an optimal a lane reservation. As to select lanes reservation for completing travel task within the given time, its objective is to minimize the total impact on all reserved lanes on unreserved ones.

However, the above lane reservation problems are practical applications in transportation and there are not many theoretical studies about probelems of optimal selection to minimise traffic impact of ones. Wu et al. [22] firstly put forward the lane reservation problem in time constrained transportation (LRPTCT) for large-scale sport games, and built a model and study the heuristic algorithm. Later, Fang et al. [23-25] studied optimal algorithm for LRPTCT. In summary, the objective function is broadly similar from these researches, which greatly simplify the complexity of the problem. The lane reservation problem for urban tourism not only needs to form a network and also to consider the influence function closer to reality.

2. Problem description and formulation

2.1 Problem description

TUST can be described as a directed network graph $G=(V,E)$, consisting of a set of $V=\{1,2,3,\cdots,n;\}$ node and a set of $E=\{(i,j)|i,j\in V\}$ directed arcs. The urban roadd intersection can be viewed as a node and a road link can be viewed as a directed arc in the transportation network.

In the paper, we define the properties of each directed arc as a set of w_{ij}, including m_{ij}, dt_{ij}, λ_{ij}, and θ_{ij} and l_{ij}. Let m_{ij}, dt_{ij}, λ_{ij} ,and θ_{ij} and l_{ij} be the number of lanes on road (i,j), design travel time, traffic saturation coefficient, actual travel time, road grade and the length of road, respectively. Traffic saturation coefficient is the ratio of road (i,j) on traffic volume (vehicles / hour, Q_{ij}) and the actual capacity by (veh / h, P_{ij}). According to BPR suggested by the Federal Highway Administration and various correction function model, t_{ij} is computed by use of formula (1).

$$t_{ij}=dt_{ij}\left[1+\alpha(Q_{ij}/P_{ij})^{\beta}\right]=dt_{ij}\left[1+\alpha(\lambda_{ij})^{\beta}\right] \qquad (1)$$

α and β as road resistance codfficient are 0.15 and 4 in the study. When the value of t_{ij} on road (i,j) is more than three times dt_{ij}, traffic will be in serious. Thus, $\lambda_{ij}=2.34$ can be calculated and it is not suitable to set up lane reservation. To simplify the calculations, we assume that each lane of traffic volume and capacity are the same. The conclusion can be drawn that the value of t_{ij} on each lane section is equal, as shown in equation (2).

$$t_{ij} = dt_{ij}\left\{1+\alpha\left[(Q_{ij}/P_{ij})/m_{ij}\right]^{\beta}\right\} = dt_{ij}\left\{1+\alpha\left[Q_{ij}/\left(p_{ij}m_{ij}\right)\right]^{\beta}\right\} \tag{2}$$

p_{ij} is actual capacity of single lane on formula (2).

In the lane reservation problem, $t^{1}{}_{ij}$ and $t^{0}{}_{ij}$ are defined as the travel time from node i to node j on reserved lane and on non-reserved lane, respectively. Because the problem that special vehicle affected by other ones rarely occurs on reserved lane, the value of $t^{1}{}_{ij}$ is produced by use of formula (3). The road grade includes urban expressway ($\theta_{ij}=1$) and trunk road($\theta_{ij}=2$).

$$t^{1}{}_{ij} = \begin{cases} dt_{ij}/1.2, & \theta_{ij}=1 \\ dt_{ij}/1.5, & \theta_{ij}=2 \end{cases} \tag{3}$$

When reserved lanes are planned on road (i, j), the remainder of lanes must be charged with other vehicles. Thus, we can compute the value of $t^{0}{}_{ij}$ through formula (4).

$$t^{0}{}_{ij} = dt_{ij}\left\{1+\alpha\left(\left(\frac{Q_{ij}}{m_{ij}-1}\right)/p_{ij}\right)^{\beta}\right\} = dt_{ij}\left\{1+\alpha\left[\lambda_{ij}\left(\frac{m_{ij}}{m_{ij}-1}\right)\right]^{\beta}\right\} \tag{4}$$

UTST needs to meet the following conditions of the transport network. Firstly, there is a node as source starting new travel. Secondly, there are m nodes as destinations, which are tourist spots in tourism urban. Thirdly, all tasks are completed within the given time. For example, figure 1 where there are a tasks set of $K=\{(1,5),(5,9),(9,11),(11,1)\}$ is the urban transportation network of Luoyang in China. Tourists spend total time within the given three hours in the lane reservation network for tourism.

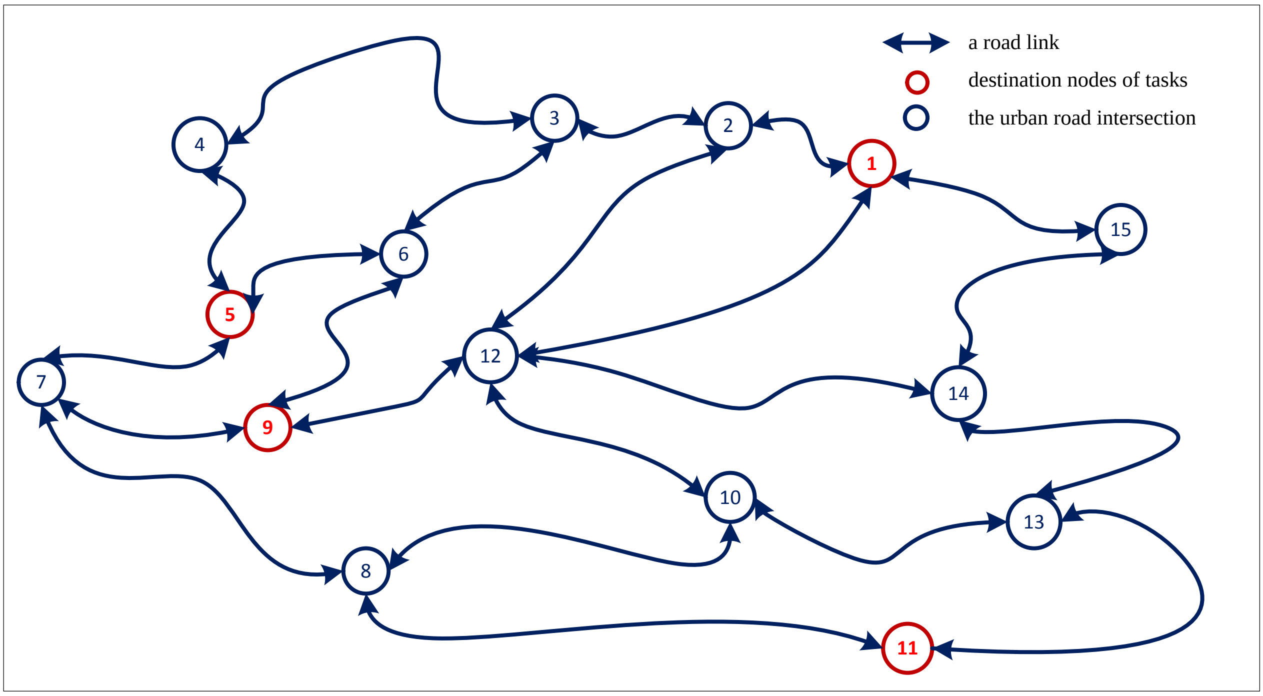

Figure 1. The urban transportation network of Luoyang

2.2 Mathematical formulation

To study well the problem, we make some assumptions. First, each arc is two way and has at least two lanes in the same direction arc, allowing one lane to be reserved. Second, the lanes are identical in the same arc, such as the travel time and traffic volume and capacity etc.. Third, there is at most one-lane reservation in each arc. Fourth, it is not considered that the lane reservation affects the drivers' preferences. Under the above assumptions, the number of the lanes for other vehicles will be reduced to $m_{ij}-1$ when one lane on road (i, j) is reserved for tourism. If the traffic volume of other vehicles remains unchanged, it will inevitably be affected by the lane reservation. The relative rate of change in travel time on unreserved lanes can reflect the traffic impact of the reserved lanes to road (i, j). We define σ_{ij} as the traffic impact of the reserved lanes on road (i, j) (TIRLR), as shown in equation (5).

$$\sigma_{ij} = \frac{t^{0}{}_{ij} - t_{ij}}{t_{ij}} \times 100\% \tag{5}$$

According to the feature of TUST, some notations are are listed as follows.

Parameters:

V: set of the urban road intersection

E: set of an directed path in the transportation network

S : set of source nodes of tasks

D : set of destination nodes of tasks

K : set of tasks $k \in K$

σ_{ij} : traffic impact of a reserved lane on road $(i, j) \in V$

l_{ij} : the length of road (i, j)

t_{ij} : the actual travel time of vehicles on road (i, j)

t_{ij}^0 : the travel time of ordinary vehicles on non-reserved lane

t_{ij}^1 : the travel time of tourism vehicles on reserved lane

m_{ij} : the number of lanes on road (i, j)

λ_{ij} : traffic saturation coefficient on road (i, j)

θ_{ij} : the grade of road (i, j)

p_k : travel time constraint for the k task

Variables:

$$u_{kij} = \begin{cases} 1 & \text{if a lane on road}(i, j) \text{ is in the path of task } k \\ 0 & \text{otherwise} \end{cases}$$

$$x_{kij} = \begin{cases} 1 & \text{if a lane on road}(i, j) \text{ is in the path of task } k \text{ and the lane is reserved} \\ 0 & \text{otherwise} \end{cases}$$

$$Z_{ij} = \begin{cases} 1 & \text{there is a reserved lane on road}(i, j) \\ 0 & \text{otherwise} \end{cases}$$

$$\min \sum_{(i,j)\in E} \sigma_{ij} l_{ij} Z_{ij} \qquad (6)$$

$$x_{ij}\left(\lambda_{ij} m_{ij} / (m_{ij} - 1)\right) \le 2.34$$

$$(\forall (i, j) \in E, \lambda_{ij}, m_{ij} \in w_{ij}, w_{ij} \in W) \qquad (7)$$

$$\sum_{j:(i,j)\in E} u_{kij} = 1 \quad (\forall k \in K, i = s_k, s_k \in K) \qquad (8)$$

$$\sum_{i:(i,j)\in E} u_{kij} = 1 \quad (\forall k \in K, j = d_k, d_k \in D) \qquad (9)$$

$$\sum_{j:(i,j)\in E} u_{kij} = \sum_{i:(i,j)\in E} u_{kij} \quad (\forall k \in K, \forall i \ne s_k, d_k) \qquad (10)$$

$$x_{kij} \le u_{kij} \quad (\forall k \in K, \forall (i, j) \in E) \qquad (11)$$

$$\sum_{(i,j)\in E} (t_{ij}^1 x_{kij} + t_{ij}^0 (u_{kij} - x_{kij})) \le p_k \quad (\forall k \in K) \qquad (12)$$

$$x_{kij} \le Z_{ij} \quad (\forall k \in K, \forall (i, j) \in E) \qquad (13)$$

$$u_{kij}, x_{kij} \in \{0,1\} \quad (\forall k \in K, \forall (i, j) \in E) \qquad (14)$$

$$Z_{ij} \in \{0,1\} \quad (\forall (i, j) \in E) \qquad (15)$$

The objective function (6) is to minimize the traffic impact of all reserved lanes on TST. Constraint (7) represents that the lane is not reserved on the road where the traffic congestion is really serious. Although function (1) has been related to traffic saturation coefficient, constraint (7) is a guarantee not to reserve the lane in the crowded roads. Constraint(8) means that each task must be leave from its source point. Constraint(9) means that each task can reach its destination point. Constraint(10) means that each task does not turn back and must move on from the node to achieve the destination point when it enters an intermediate node. Constraint(8-10) indicates that there is at least one path for each task form its source point to destination point. Constraint (11) means that there is a reserved lane in road (i, j) only if task k uses this lane. Constraint (12) is the travel duration constraint. Constraint (13) means that there is a reserved lane to road (i, j) in the path of task k if and only if this lane is reserved. Constraints (14)–(15) are about the constraints on the decision variables.

2.3 Model comparison

The model in the paper has the same meanings about the corresponding decision variables and the objective function in other research articles [22,23], which is to minimize the traffic impact of all reserved lanes, but there are several different from other models. First, the model is based on UTST, which is a closed network consisting of a series of the reserved lanes. Second, the overall goal of UTST is broken down into the set of task within given the degree of tourist satisfaction. Third, the objective function in the model is the key to solve the problem; we find that Wu and Fang define $t_{ij} m_{ij} / (m_{ij} - 1)$ as TIRLR, which is not only difficult to obtain by scientific measurement but also not non-dimensional; in order to make the model closer to reality, the design travel time and the traffic saturation coefficient are introduced to construct the objective function, which is very easy to obtain in reality. Fourth, each TIRLR is obtained by unitary processing in accordance with the actual travel time of vehicles on road (i, j), and we easily compute the objective function by multiplying each TIRLR and the weight of road.On the whole, the model can describe well on the real problem of UTST.

3. Numerical example and solution approach

In order to verify the effectiveness and superiority of the model, the paper takes the transportation network of Luoyang(figure 1) for instance to compute and test, and each directed arc’s properties are shown in Table 1. There is a set of tasks $K = \{(1,5),(5,9),(9,11),(11,1)\}$ in the urban transportation network of Luoyang in China. LINGO is one of the best choices to solve the optimization model, for the advantages of the simple modeling and solving speed etc. Mathematical structure and properties on the model can be automatically identified by LINGO, which can decide to use which model to and what kind of solving method. The example of the optimization is small-scale solution, we can use LINGO in the solution of model. The two results are shown in table 2 by the methods studied before and current method.

As shown in the table 2 and figure 2, except for k_1, these tasks are not similar to the path of lane reservation by two methods. In reality, road (13,14) and road (8,11) are the more important roads in LuoYang. The new model avoids reserving two roads, but they are reserved to lane reservation by the method studied before. Thus, the model in this paper has better superiority and effectiveness.

Table 1. Directed arc's properties in the transportation network

NO	Source node	Destination node	$w_{ij}(m_{ij}, dt_{ij}, \lambda_{ij}, \theta_{ij}, l_{ij})$	NO	Source node	Destination node	$w_{ij}(m_{ij}, dt_{ij}, \lambda_{ij}, \theta_{ij}, l_{ij})$
1	1	2	(4,3,1.208,2,2)	12	7	9	(2,5,0.946,2,4)
2	1	12	(2,20,1.121,2,10)	13	7	8	(3,25,1.066,2,20)
3	1	15	(3,15,1.096,2,12)	14	8	10	(4,12,0.846,1,12)
4	2	3	(4,3,0.684,1,3)	15	8	11	(4,22,1.277,2,17)
5	2	12	(3,15,1.034,2,10)	16	9	12	(2,5,1.123,2,4)
6	3	4	(2,15,0.678,1,16)	17	10	13	(3,12,1.198,2,9)
7	3	6	(3,14,0.958,2,7)	18	11	13	(4,30,1.356,2,24)
8	4	5	(4,8,1.206,2,5)	19	12	14	(2,20,0.841,2,16)
9	5	6	(2,10,1.332,2,5)	20	12	10	(4,20,1.222,2,16)
10	5	7	(3,15,1.171,2,10)	21	13	14	(3,20,0.835,2,16)
11	6	9	(3,12,0.859,1,9)	22	14	15	(2,17,1.091,2,13)

Table 2. The comparison of consequences on Lane reservation

Task	Source	Destination	Reserved Lane	
			Methods Studied Before	Current Method
k_1	1	5	1-2-3-4-5	1-2-3-4-5
k_2	5	9	5-7-9	5-6-9
k_3	9	11	9-12-10-8-11	9-7-8-11
k_4	11	1	11-13-14-15-1	11-13-10-12-1

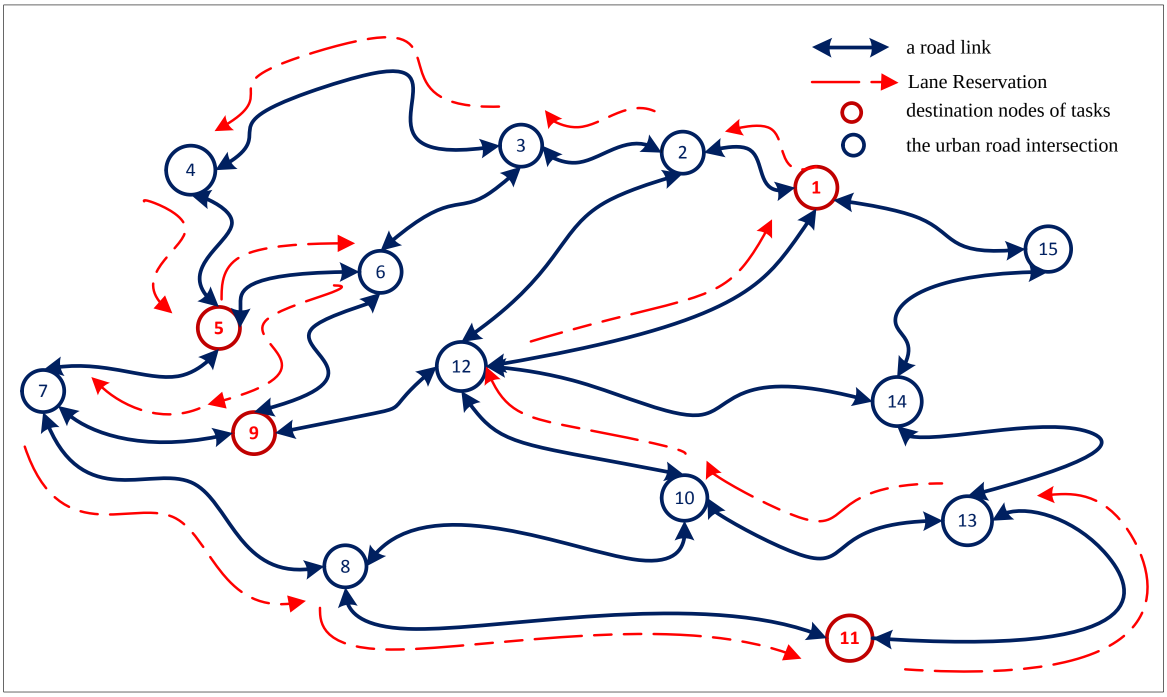

Figure 2. The network of lane reservation in Luoyang

4. Conclusions

This paper has investigated an urban transportation network problem for tourism via lane reservation strategy. By translating the level of customer satisfaction into a time constrain, the problem has become the optimal problem of lane reservation on urban transportation network. The design of travel time and the traffic saturation coefficient is easier than other data to obtain enhances the effectiveness and superiority of the model. The results have shown that it is very close to reality by Lingo in the example of the tourist urban of Luoyang about the objective function, constrain of task and measure of making reservation lane in the model.

It is desirable to further apply new algorithms to solving those larger and more complex real-world optimization problems. At the same time, due to the dynamic characteristic of traffic saturation coefficient, the problem will become a dynamic optimization problem. These will be our further work.

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