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FLEET OPTIMIZATION FOR LAST MILE TRANSPORT

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Shared-ride taxi is one of the best substitutions to resolve last mile problem, which has been highlighted as a crucial factor that affecting transit use. However, the existing literatures focusing on the fleet optimization of taxi in the context of last mile ride sharing is relatively limited. Thus, a proper fleet planning model for shared-ride taxi service should be developed. This paper proposed a bi-objective shared-ride taxi model, with the aims to maximize operator's profit while minimizing the travel cost of passengers. The proposed model is optimized by considering numerous practical constraints, including stochastic demand and shared-cost constraints. An illustrative case study is performed to optimize the last mile travel from Sungai Buloh MRT station to four destinations (i.e. one to many last mile problem) in order to meet the needs of passengers. The developed model is solved by using branch and cut algorithm with the aid of CPLEX optimization software. Results shows that 88% of the requests is satisfied with 12.79% of savings to the passenger cost per trip. It is anticipated that the proposed model to reveal some positive visions to tackle last mile shared-ride problem which is more beneficial to the operator's as well as the users.

Keywords: fleet planning, last mile problem, shared-ride taxi, service optimization.

1 Introduction

Last mile problem refers to the difficulty of public transport users to egress from the transportation networks to their destination locations (Mineta Transportation Institute, 2009). The difficulty arises mainly due to transportation schedule, capacity, cost, comfort, route, passenger waiting and travel time. In the traditional last mile problem, the customer-taxi assignment decision is usually considered. Loporte (1992) discussed an overview of exact and approximate algorithms for customer-vehicle assignment. There are numerous relevant studies on last mile problem. For instance, Lin, et al. (2012) optimized shared-ride taxi services by considering the interests of both taxi drivers and passengers. By adopting a heuristic approach, Santos and Xavier (2015) maximized the number of passenger requests and minimizing the total value paid by all passengers. Boyacı, et al. (2015) developed and solved a multi-objective MILP model for one-way vehicle-sharing systems by taking into account vehicle relocation and electric vehicle charging requirements. Fahnenschreiber, et al. (2016) solved a dynamic ride-sharing service between two train rides by connecting public transport stations and the respective offers of the drivers. In the same year, Liang, Almeida and Arem (2016) optimized an automated taxi (AT) system for the last mile travel of train trips by using Mix Integer Programming (MIP) algorithm. Recently with the objective of minimizing passenger waiting and riding time Wang (2017) develop exact MIP model for last-mile transport system. In contrast to the existing studies, this paper aims to develop a bi-objective optimization model for shared-ride taxi operation for which the economic benefits of the taxi operator as well as the passengers are taken into consideration explicitly. The proposed bi-objective model is important to assure the benefits of supply and demand. Specifically, this paper includes the shared-cost of passenger as one of the objectives (with the goal to minimize the travel cost of passengers) while maximizing the profit margin of taxi operator.

The remainder of the paper is organised as follows. Section 2 presents the mathematical model formulation for the bi-objective optimization model. Section 3 illustrates the case study with the discussions on the resultant findings. Section 4 concludes the paper with some suggestions for further research.

2 Mathematical Model Formulation

In this section, the formulation of bi-objective model (with the aim to maximize taxi operator's profit while minimizing the passengers shared cost) is presented.

2.1 List of notations

Input Parameter	*Description*
N	Number of daily request
V	Number of destination
T	Maximum time instant for the service period
P_{km}	Price rate per driving distance
F	Fleet size
C_{ph}	Taxi purchase cost
C_{mn}	Taxi maintenance cost
C_{dp}	Taxi depreciation cost
C_{pk}	Parking cost
PK_0	Number of parking spot
C_{dr}	Salary of taxi driver
E_c	Expected operational cost
C_{km}	Taxi travel cost per driving distance
L_{r^i}	Total number of passengers
$L^f_{u+1'}$	Number of passengers get off from taxi f at the next destination $u+1$
C^f_0	Capacity of taxi f at MRT station
$d^f_{u,u+1}$	Distance travel by taxi f between destination u and $u+1$
α	Significant level
B^f_u	The beginning time of taxi service f at destination u
sd	Service duration
q^k	The maximum capacity of taxi k
D_{r^i}	The earliest departure time
A_{r^i}	The latest arrival time

Performance Measure	*Description*
P	Total profit
S_{r^i}	Shared cost of passenger per request

Inter-mediate variables	
R	Total operating revenue
C	Total operating cost
S_i	Maximum value that the passengers are willing to pay
L^f_u	Number of passengers in taxi f at destination u
f^t_0	Number of available taxi at MRT station at time instant t
$t_{u,u+1}$	Travel time between destination u and $u+1$

Set	*Description*
$I = \{1,2,...N\}$	The set of request received to travel from the MRT station (per day)
$J = \{1,2,..., F\}$	The set of taxi

$K = \{1,2,...,V\}$	The set of destination location of passenger
$U = \{0,1,...V\}$	The set of MRT station and destination location
$t = \{0,1,...,T\}$	The set of time instant for the operating period

Decision variable

$$r^i = \begin{cases} 1, \text{if the passenger request } i \text{ is statisfied} \\ 0, \text{otherwise} \end{cases}$$

2.2 *Bi-objective optimization model*

The first objective of the model is to maximize operator's daily profit (P). For every request i, P is obtained by getting the difference of daily operator's operating revenue (R) and operator's operating cost (C). This objective can be expressed as below.

Objective 1, OBJ_1**:** Maximize the operator's profit

$$OBJ_1 = Max\left[\left(P_{km} - C_{mn}\right) \sum_{i \in I} \sum_{f \in J} \sum_{u \in K} d_{0,u}^{f} r^i + C_{pk} PK_0 + \left[\left(C_{ph} + C_{dp} + C_{dr} + E_c \right) \times F \right] \right] \quad (1)$$

In order to meet request i, the operator's operating cost C includes taxi maintenance cost, parking cost, purchase cost, depreciation cost, driver's salary and also expected operational cost.

As shown below, the second objective is to minimize the shared cost of passenger $\left(S_{r^i}\right)$. For this objective, the travel cost of taxi, total number of passenger and also the quantity of passenger in taxi after serving a respective destination is considered simultaneously.

Objective 2, OBJ_2: Minimize the shared cost of passenger

$$OBJ_2 = Min\left[\sum_{f \in J} \sum_{u \in U} \frac{\left(r^i C_{km} d_{u,u+1}^{f} \right) L_{r^i}}{L_u^f} \right] \quad (2)$$

Thus, the objective function of the bi-objective optimization model can be expressed as below.

$$Opt\left[OBJ_1, OBJ_2\right] \quad (3)$$

2.3 *Practical Constraints*

The developed model is optimized subject to following practical constraints.

Fleet size constraint At the beginning and the end of taxi operations, it is important to note that all taxi are stocked at the MRT station. This constraint can be expressed as follows:

$$f_0^t = F \quad (4)$$

Parking capacity constraint At any time instant, it is necessary for the parking capacity of taxi to be sufficient at the MRT station. This constraint can be formed as below:

$$f_0^t \leq PK_0 \quad (5)$$

Service constraint This constraint assures that the satisfied request must not be more than the total number of request from the passengers. This constraint can be expressed as follows.

$$r^i \leq Nr^i \tag{6}$$

Stochastic demand constraint This constraint is necessary to meet a satisfied level of demand (for a desired level of service). Stochastic demand constraint can be expressed as below.

$$\sum_{i \in I} r^i \geq (1-\alpha)N \tag{7}$$

Operating time constraint Operating time constraint is required to indicate the beginning time of taxi service at the next destination u+1 $\left(B^f_{u+1}\right)$. The beginning time of taxi service at next destination $u+1$ $\left(B^f_{u+1}\right)$ take the beginning time of taxi service at the destination $u\left(B^f\right)$, travel time from destination u to the next destination $u+1$ $\left(t_{u,u+1}\right)$, and service duration (sd) into computation. Besides, the constraint is also required to capture the earliest departure time and the latest arrival time of passengers. For each request, the beginning time of taxi service at MRT station $\left(B^f_{0,r^i}\right)$ are equal to the taxi service time for that request. This ensure the multiple service can be provided by each the taxi. The respective constraint can be formed as follows:

$$B^f_{u+1} r^i \geq \left(B^f_u + t_{u,u+1} + sd\right) r^i \tag{8}$$

$$D_{r^i} \leq B^f_{0,r^i} \leq B^f_{u,r^i} \leq A_{r^i} \tag{9}$$

Number of passengers constraint This constraint captures the number of passengers in the operating taxi after it serves destination u. This constraint involves the number of passengers in taxi at destination u, number of passengers get off from taxi at the next destination $u+1$. The destination u sorted according to the sequence it will be served, where destination u will be served first before destination $u+1$. Number of passenger constraint can be formed as below.

$$L^f_{u+1} r^i = \left(L^f_u - L^f_{u+1'}\right) r^i \tag{10}$$

Capacity constraint In order to provide a feasible shared-ride service, capacity constraint can be formed as below (subject to the maximum capacity of taxi).

$$2 \leq C^f_0 \leq q^k \tag{11}$$

Shared cost constraint With the aim not to exceed the maximum value that the passenger is willing to pay, shared cost constraint is formed as below.

$$S_{r^i} \leq S_i r^i \tag{12}$$

2.4 *Solution Algorithm*

In terms of the solution algorithm, the developed bi-objective model is first converted as a single-objective model (for the ease of solution) as shown in Eq. (13). This is done by using a scalarization technique, by considering a weighted sum (λ) which varies from 0 to 1. Then, branch-and-cut method is used to obtain the desired solutions (Correia and Antunes, 2012; Liang, Almeida and Arem, 2016).

$$OBJ = Max\left[\lambda\left(\left(\sum_{i \in I}\left(S_i r^i - S_{r^i}\right)\right) + OBJ_1\right)\right] \tag{13}$$

The sub-problem identify the minimum shared cost of passengers for each request. Then the master problem find an optimal of the single-objective model. In order to capture customer-taxi assignment in the sub problem, the insertion heuristic algorithm (based on the farthest destination) is adopted to assign the taxi and customer (Loporte, 1992). The optimization model were solved by Cplex sofware.

3 An Illustrative Case Study

The developed model is applied to a simple case study in order to solve the last mile travel from Sungai Buloh MRT station to four destination locations, namely Sungai Buloh, Bukit Rahman Putra, Kampung Paya Jaras and Sungai Pelong. Note that 24-hour booking period is required to use the shared-ride service. And, the operating period of the taxi is 6 in the morning until 12 midnight. The service time are selected according to the maximum arrival time of train at the MRT station which are 15 minutes In order to travel between the respective locations, the estimated travel distance and time are presented in Tables 1 and 2.

Table 1. Travel distance (in kilometres).

Location	Sungai Buloh MRT station	Sungai Buloh	Bukit Rahman Putra	Kampung Paya Jaras	Sungai Pelong
Sungai Buloh MRT Station	-	3.3	3.8	4.6	7.8
Sungai Buloh	3.3	-	1.4	3.5	5.9
Bukit Rahman Putra	3.8	1.4	-	4.1	5.2
Kampung Paya Jaras	4.6	3.5	4.1	-	3.9
Sungai Pelong	7.8	5.9	5.2	3.9	-

Table 2. Travel time (in minutes).

Location	Sungai Buloh MRT station	Sungai Buloh	Bukit Rahman Putra	Kampung Paya Jaras	Sungai Pelong
Sungai Buloh MRT Station	-	2.5	2.9	3.5	5.9
Sungai Buloh	2.5	-	1.1	2.6	4.4
Bukit Rahman Putra	2.9	1.1	-	3.1	3.9
Kampung Paya Jaras	3.5	2.6	3.1	-	2.9
Sungai Pelong	5.9	4.4	3.9	2.9	-

Besides, some other inputs considered for the case study include $q^k = 4$, $sd = 0$, $P_{km} = RM$ *1/km*, $C_{mn} = RM$ *0.35/km*, $C_{pk} = 0$, $C_{km} = RM$ *0.65/km* with the base rate of RM5 (include earlier booking charges), $F = 5$, $C_{dp} = RM$ *40/day*, $C_{ph} = RM$ *20/day* and $C_{dr} = RM$ *100/day*. Due to the lack of the relevant input for the number of passengers, the number of passengers travelling (from MRT station) to the four destination locations are generate randomly.

3.1 Results and Discussion

The overall computation time of the case study is less than two minutes for the master and sub-problems. It is expected that the computational time will increase if more instances with diverse input values be consider. From the obtained solutions, it can be seen that although the fleet size is small (i.e. 5 taxis for the daily service), 88% of passenger requests are satisfied (64 requests) for the daily operation. This would generate a profit margin for the taxi operator up to RM1073 (i.e. daily profit) with a total operating cost of RM2895.90 daily. By application of shared-ride taxi, the total shared cost of passenger is RM3968.90 (i.e. daily total revenue of operator) with saving of RM579.40 daily to the total passengers travel cost. For individual passenger, the resultant findings showed that the estimated amount of shared cost is RM6.00 per trip (in average) and this in fact would contribute to a savings of 12.79% for each passenger request. For the passenger requests which are rejected for shared-ride services, this happened because the willingness to pay of the passenger is not met (i.e. shared cost constraint is not satisfied).

4 Conclusions

This study developed a bi-objective optimization model to optimize last mile travel by considering both supply and demand aspects for which the operator's profit and also passengers travel cost are captured explicitly. The results of the case study showed that the proposed model would produce a promising outcome not only to the taxi operator but also the passengers. In other words, the proposed study is able to assure a win-win situation for the stakeholders (i.e. taxi operators and passengers). In overall, 88% of daily passenger requests are accepted to assure the maximal profit of operator and also the minimal travel cost of passenger. However, there are some shortcomings to be tackled in the future research. A diverse input values will be considered for future works in order to yield more relevant findings. The developed model can be extended to capture more operational concerns including some uncertainty elements, for instance passenger behaviour/perception and traffic condition.

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