BUS REALLOCATION PROBLEM IN NETWORKS WITH OVERLAPPING ROUTES.

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Abstract. Bus systems in Vietnam characterized by networks with overlapping routes have recently been too overloaded with passengers every day at peak times. This paper addresses the overloading problem by trying to share buses and then reallocate buses among all routes. Specifically, our objectives include minimizing the bus operating cost and number of buses used. The model is subjected to the number of buses available, and capacity to carry all passengers on the network, and minimum number of trips for each bus route. Furthermore, an IP and IBM Cplex were then introduced to formulate and solve the model. The research was applied and expected to improve the bus service in Ho Chi Minh city, Vietnam.

Keywords: Bus reallocation, IP, IBM Cplex.

1. INTRODUCTION

With the fast growing of civilians nowadays, private vehicles such as motorbikes, motorcycles, cars, vans, etc. have been more and more in demands. The growth, however, has not been in pace with the growth of public infrastructure such as road expansion or designing new public routes. As a result, there appears traffic jams, congestion in many places in Vietnam during peak hours. Commonly, public transportation including bus system is an effective way to solve traffic problems and it is an important means of transportation in city. Particularly, bus system in Vietnam is a means of low-cost, flexible and convenient public transportation. However, the bus service in Vietnam also has some problems, one typical among them is the unbalanced utilization of buses among many bus routes. Currently, the policy is to assign a specific number of buses for each route, each vehicles on a bus route is labelled with the route number and therefore cannot share to the other routes. As a result, with different customer demands, some routes are extremely crowed while the other idle or in normal condition.

Within the operation of public transport systems, especially in congested systems, it is vital to properly plan and design headways and the required fleet size. The importance of proper planning is even greater if the system is going to be implemented for the first time or if an existing system is going to be restructured (Muñoz et al. 2009). There are currently a variety of bus transit vehicle types that are suitable for different types of cities, services, and operations, and the bus size clearly has a direct effect on the operating costs. However, with the exception of congested networks, operating costs are known to be opposed to user costs (Alonso et al. 2011), so the transit system should be designed to minimize operating costs and the generalized user costs.

Recently, there have been many research on the bus scheduling/reallocation problems, which give optimization models that minimize the sum of costs from passenger and bus companies, number of buses used or finding an optimal headway so that the customer waiting time is minimized while maintaining the low cost in bus operation. Basically, solutions to this problem are often mathematical, heuristics, artificial intelligence, and evolutionary algorithms. In this study, objective is to find the optimal number of buses in case of pooling buses among many bus routes. According to Chompoonoot et al (2015), in the bus problems, there are bus routes and bus trips. Particularly, in one specific route, there are many trips starting at different periods of time. Furthermore, the decision variables for their model were the number of buses needed for each bus route and also a binary variable indicating if a bus of a certain route was assigned to a trip then continue with another trip. The study was applied to a private bus company which covered 9 routes with 35 trips in total. Following their studies on the application of IP in bus planning and scheduling, the model was adopted in our study and then applied to a bigger bus problem having 10 routes with more than 60 trips for each route in our country.

The remaining sections of the research paper are organized as follows. In section 2, the relevant literatures on the bus scheduling problems were reviewed. Next, section 3 presents the model development. In section 4, we provided a case study to illustrate the proposed methodology. Finally, the conclusion and further related studies was stated in section 5.

2. LITERATURE REVIEW

There have been many researches related to the optimal bus scheduling. Farhan et al. (2005) proposed a genetic algorithm based bus scheduling model for a transit network problem. The bus scheduling problem was solved under two levels; the minimum frequency of buses required on each route with the load feasibility was first determined by considering each route individually, then the fleet size from the first level was taken as upper bound and fleet size was again minimized by considering all routes together. Moreover, they also provided a GA technique to solve their model.

A Demand and Travel Time Responsive (DTR) was proposed by Makrand et al. (2013) to solve a real-time optimal bus scheduling problem. They considered both bus stop and route segments of the problem in an integrated manner. Moreover, different real time data event parameters (e.g. bus stop departures and arrivals for buses operating on a line- based time-table and bus traffic cost were applied to optimize the scheduling process.

Anthony and Nigel (1981) developed a model which recognized passenger route choice behavior, and seeks to minimize a function of passenger waiting time and bus crowding. The model's constraints were the number of buses available and the provision of enough capacity on each route to carry all passenger selecting it. Moreover, they also proposed an algorithm which was developed based on the composition of the decomposition of the problem into base allocation and surplus allocation components.

Angel et al. (2013) proposed an optimization model for designing the headways and sizes of buses circulating on public transport networks. The model aims to minimize the system's operating and user costs. Additionally, it takes into account congestion on the public transport system and works by considering elastic demand. In the end, according to the authors, the consideration of elastic demand is shown to be beneficial in response to proposed operational changes rather than the assumption of a fixed and know public transport trip matrix.

Neeraj et al. (2013) developed a resource scheduling model which can improve the performance of transportation system. The proposed model minimizes the waiting time of passengers at stops and also minimizes the number of buses required. Moreover, its constraints include load factor, time constraint, and frequency constraint. The model can be flexible in terms of frequency; it will help to increase the frequency if the demand for service is more and reduce the frequency if demand is less and save considerable amount of money for the agencies. Also, it is expected to provide economical and efficient use of fleet resource and provide safe and fast mode of transport to the passenger needs.

Somnuk and David (2003) proposed a new model showing how genetic algorithms can be manipulated to help optimize bus transit routing design, incorporating unique service frequency settings for each route. Particularly they developed seven genetic operators which were designed for facilitating the search within a reasonable amount of time. In addition, headway coordination is applied by the ranking of transfer demands at the transfer terminals. The proposed methodology was applied on a benchmark network to test its efficiency, and performance results are presented. The result showed that the proposed model was more efficient than the binary-coded genetic algorithm benchmark, in which problem content cannot be utilized.

Chompoonoot et al (2015) developed an IP model for solving a bus scheduling problem. Particularly, they considered the pooling buses among the existing routes so that the company will utilized buses as much as possible. The research resulted on 18.52 % reduction of the number of buses used and 5.6% reduction of the total cost. Moreover, a simulation model was also developed to evaluate the solution using real demand of the year 2014. Moreover, another integer programming model was also developed by Dirk et al (1995). They proposed two heuristic methods, one of which was based on linear programming and the other was a straightforward derivation of common bus operation practice The proposed methodology was then tested on two selected bus routes in Bangkok and extensive comparisons are made. The test resulted on the simultaneous reduction on the exploitation costs and improve service to the public. Further, the methodology allows the bus company to systematically plan all its bus frequencies and to allocate buses to routes in a much more efficient way than at present.

T. Bektaş and Seda Elmastaş (2007) proposed an exact solution approach for solving a real-life school bus routing problem (SBRP) for transporting the students of an elementary school throughout central Ankara, Turkey. Particularly, an IP model was developed to formulate the problem as a capacitated and distance constraint open vehicle routing problem. Moreover, the research showed that the model can result in a saving of up to 28.6% in total travelling cost as compared to the existing implementation.

To sum up, there have been many research regarding to the bus scheduling problems all over the world, which has continuously improved bus networks. As can be seen, the application of IP model in solving the bus problem has been more and more common with its simplicity and ease of use. With regards to the bus scheduling, in Vietnam, however, none or little research has been conducted on that kind of problem. Plus, the bus problems are now being considered as one of the most urgent problems in HCMC, Vietnam; buses are the transportation means which can reduce the pollution and traffic congestion in HCMC. Meanwhile in Vietnam, the trend of bus usage in HCMC is decreasing, which is therefore, not good for the city civilians in the long run.

Based on the prior studies on the application of IP model in solving the bus problems, especially the study of Chompoonoot et al (2015), we have found an opportunity to apply on the bus scheduling problems and contribute to the scheduling knowledge in the bus problems in Vietnam.

3. MATHEMATICAL MODEL

3.1 Notation

- Decision variables:

B_i: number of buses for each route i.

$$X_{ijk} = \begin{cases} 1, & \text{when a bus of route I was assigned to trip j and then can serve trip k} \\ 0, & \text{otherwise} \end{cases}$$

- Parameters:

Co_{ij} : Operating cost per distance of route i of trip j

F_i : Fixed cost of route i

D_{ij}: Distance of route i of trip j

N_{ij}: Maximum number of trips per day for each bus of route i of trip j

R_{ij}: Minimum number of trips for route i

NB: Number of buses available.

$$A_{ijk} = \begin{cases} 1, & \text{when a bus of route i was assigned to trip j and then can serve trip k} \\ 0, & \text{otherwise.} \end{cases}$$

3.2. Mathematical model

$$\text{Min Cost} = \sum_{i}^{R}\sum_{j}^{T}\sum_{k}^{T} (Co_{ij}D_{ij}A_{ijk}X_{ijk} + F_i) \quad (1)$$

$$\text{Min number of buses used} = \sum_{i}^{R} B_i \quad (2)$$

Subject to

- $\sum_{k=1}^{T} A_{ijk}X_{ijk} \leq N_{ij}$ for every i, j (3)
- $\sum_{j=1}^{T} A_{ijk}X_{ijk} = 1$ for every i, k (4)
- $\sum_{j=1}^{T}\sum_{k=1}^{T} A_{ijk}X_{ijk} \geq R_i$ for every i (5)
- $\sum_{j=1}^{T}\sum_{k=1}^{T} A_{ijk}\frac{Xijk}{Nijk} \leq B_i$ for every i (6)
- $\sum_{i=1}^{R} B_i \leq NB$ (7)
- $B_i \geq 1$ for every i (8)
- All B_i are integer (9)
- All X_{ijk} and A_{ijk} are binaries (10)

Objective function (1) aims to minimize total cost including variable and fixed cost to operate the bus. Further, the function (2) also aims to minimize number of buses used daily.

There are eight constraints for this model, the (9) and (10) constraints ensure the integer and binary property of some parameter and decision variables. Equation (3) ensures to limit the number of trips for each route i starting at trip j. Equation (4) ensures that there is only one trip from trip j continued to trip k for each route k. Equation (5) was to arrange the number of trips so that it has to be at least the minimum number of trips that the company should assign based on the government regulation. Equation (6) defines the number of bus for each route i. Finally, Equation (7) ensures that the proposed number of buses should be less than the number of buses available.

3.3. Model Assumptions

- The daily demand and headway of each route are assumed to be deterministic.
- There is only one trip j that can continue to serve one trip k at a time.
- The distance and variable cost per distance of route i for every trip j are assumed to be identical.

Table 1: Value of N_{ij} - Maximum number of trips per day

	5:00	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00
Route 1	30	30	30	30	30	28	28	28	28	25	25	25	25	25	25	20	20	20	20	20	18
Route 2	30	30	30	30	30	29	29	29	29	26	26	26	26	26	26	21	21	21	21	21	19
Route 3	30	30	30	30	30	30	30	30	30	27	27	27	27	27	27	22	22	22	22	22	20
Route 4	30	30	30	30	30	31	31	31	31	28	28	28	28	28	28	23	23	23	23	23	21
Route 5	30	30	30	30	30	32	32	32	32	29	29	29	29	29	29	24	24	24	24	24	22
Route 6	30	30	30	30	30	33	33	33	33	30	30	30	30	30	30	25	25	25	25	25	23
Route 7	30	30	30	30	30	34	34	34	34	31	31	31	31	31	31	26	26	26	26	26	24
Route 8	30	30	30	30	30	35	35	35	35	32	32	32	32	32	32	27	27	27	27	27	25
Route 9	30	30	30	30	30	36	36	36	36	33	33	33	33	33	33	28	28	28	28	28	26
Route 10	30	30	30	30	30	37	37	37	37	34	34	34	34	34	34	29	29	29	29	29	27

	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:45	14:00	14:15	14:30	14:45	15:00	15:15
Route 1	18	18	18	18	18	18	18	18	18	17	17	17	17	17	17	15	15	15	15	15	15
Route 2	19	19	19	19	19	19	19	19	19	18	18	18	18	18	18	16	16	16	16	16	16
Route 3	20	20	20	20	20	20	20	20	20	19	19	19	19	19	19	17	17	17	17	17	17
Route 4	21	21	21	21	21	21	21	21	21	20	20	20	20	20	20	18	18	18	18	18	18
Route 5	22	22	22	22	22	22	22	22	22	21	21	21	21	21	21	19	19	19	19	19	19
Route 6	23	23	23	23	23	23	23	23	23	22	22	22	22	22	22	20	20	20	20	20	20
Route 7	24	24	24	24	24	24	24	24	24	23	23	23	23	23	23	21	21	21	21	21	21
Route 8	25	25	25	25	25	25	25	25	25	24	24	24	24	24	24	22	22	22	22	22	22
Route 9	26	26	26	26	26	26	26	26	26	25	25	25	25	25	25	23	23	23	23	23	23
Route 10	27	27	27	27	27	27	27	27	27	26	26	26	26	26	26	24	24	24	24	24	24

	15:30	15:45	16:00	16:15	16:30	16:45	17:00	17:15	17:30	17:45	18:00	18:15	18:30	18:45	19:00	19:15	19:30	19:45	20:00	20:15	20:30
Route 1	15	10	10	10	10	10	6	6	6	6	4	4	4	4	4	4	3	3	2	1	1
Route 2	16	11	11	11	11	11	7	7	7	7	5	5	5	5	5	5	4	4	2	1	1
Route 3	17	12	12	12	12	12	8	8	8	8	6	6	6	6	6	6	5	5	2	1	1
Route 4	18	13	13	13	13	13	9	9	9	9	7	7	7	7	7	7	6	6	2	1	1
Route 5	19	14	14	14	14	14	10	10	10	10	8	8	8	8	8	8	7	7	2	1	1
Route 6	20	15	15	15	15	15	11	11	11	11	9	9	9	9	9	9	8	8	2	1	1
Route 7	21	16	16	16	16	16	12	12	12	12	10	10	10	10	10	10	9	9	2	1	1
Route 8	22	17	17	17	17	17	13	13	13	13	11	11	11	11	11	11	10	10	2	1	1
Route 9	23	18	18	18	18	18	14	14	14	14	12	12	12	12	12	12	11	11	2	1	1
Route 10	24	19	19	19	19	19	15	15	15	15	13	13	13	13	13	13	12	12	2	1	1

4. NUMERICAL ILLUSTRATION

The model was applied to a private bus company in HCMC, Vietnam. Among many bus routes, there are 10 main bus routes circling around the center of the city. Currently, each route has their own buses, which leads to some routes get their buses overutilization while the others' are underutilization. The pooling buses among the 10 routes is proposed to reallocate buses for each route.

Particularly, each route has around 63 trips spanning from 5:00 AM to 22:00 PM. The fixed cost covers the costs of insurance, and annual taxes incurred by a vehicle of a certain bus size. The operating cost includes two types of cost: Direct cost and indirect cost. The direct cost mainly focuses on fuel cost while indirect cost includes the administration cost, personnel cost, etc in every route i and often accounts for 12% of the direct cost (Ibeas et al. 2006).

Table 2: Basic data of the ten routes

Route	Fixed Cost	Operating cost	Distance/ trip (km)	Min No. trips
1	500000	18000	33	20
2	1000000	25000	21	40
3	600000	17000	33	10
4	700000	14000	24	15
5	1000000	32000	29	50
6	1200000	25000	30	20
7	700000	33000	31	33
8	1500000	16000	29	32
9	1100000	19000	26	15
10	1400000	29000	18	30

The model was solved using IBM-Cplex. The computational time was quite short (i.e. 5.8 seconds) resulting the number of buses for each route as the following table:

Table 3: Number of buses used for each bus route

Route	Number of buses used
1	3
2	3
3	3
4	3
5	11
6	2
7	2
8	2
9	2
10	2

Table 4 : Compare current method to the proposed method.

	Current	Proposed	%Reduction
Number of buses	43	33	23%

5.CONCLUSION AND RECOMMENDATIONS

In this study, an IP model was introduced to solve a bus scheduling problem in Vietnam in case of pooling buses among bus routes. The problem included 10 bus routes with more than 60 trips for each route. The mathematical model of this problem was develop to find the minimum number of buses. The research resulted in 23 percent reduction in the number of buses used.

Practically, the study could help solve a small instance of the bus scheduling problems in Vietnam with the pooling of buses assumption and then we can use the buses more efficiently. In terms of theory, the study can be considered as a small branch of the transit network optimization whose none or just little research has been focused in Vietnam. Furthermore, the result shows that it is possible to improve the bus service by applying the optimization model. Therefore, it could encourage researchers to conduct research on this field to more and more improve the bus system in Vietnam.

The study just, however, covered a small part of the bus network in Vietnam. In order to apply to a bigger bus network, further study on heuristics and algorithm for this kind of problem is recommended. Also, in this study the headway and bus size was assumed to be deterministic and predefined. Thus, further study of finding optimal headway and bus size should be conducted so as to better improve the country bus service.

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