BUS TRAVEL TIME OPTIMIZATION WITH UNEQUAL HEADWAY PATTERN

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Introduction

In urban areas, bus networks are a major part of the public transportation system because they are easily accessible and more affordable than other types of public transportation [1, 2]. Operating costs and fixed costs are an important issue for Transit companies [3]. Also, travelling with minimum time and cost is significant for passengers [4]. Studying ways of improving the performance of bus services is important due to increasing operating costs and passenger demand [5]. Verifying the level of cost is important for optimizing public transportation [6]. A number of bus control strategies for improving the efficiency and reliability of bus systems include: bus signal priority (BSP), bus-holding, dedicated bus lanes, stop-skipping, and deadheading.

BSP is an operational tool which facilitates and eases the movement of buses through traffic signal controlled intersections in network by providing priority service opportunities to buses by implementing temporary signal timing alternation designed to reduce bus wait time and travel time at a relatively low cost to other traffic [7, 8]. Busholding can improve bus schedule reliability by decreasing disturbances to bus motion [9, 10]. In relation to the layout of routes, dedicated bus lanes can increase the reliability of bus service [11]. Bus stop skipping allows some buses to skip certain stops; this can decrease passenger waiting time and increase operation speed in the one operation cycle. On the other hand, a deadheading bus strategy

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can decrease operating costs by moving empty buses from an origin depot to a pointed stop. This paper will place more emphasis on the stop-skipping strategy. Research on optimizing bus travel time by way of stop-skipping pattern has been accomplished by many researchers, for example, by Fu and Yang (2002) [12], Furth (1985) [13] Delle Site and Filippi (1998) [14], Li et al. (1991) [15] and Sun (2005) [16]. However, in most of past studies, researchers used homogeneous temporal distribution (equal headway) and there has been a few studies on optimizing bus stop-skipping with un-equal headway.

Stop-skipping has been studied by many researchers using different assumptions and solution methodologies. Liu et al. (2013) investigated stop-skipping with random travel time in order to understand the variance of travel time instead of constant values. This particular stop-skipping strategy was developed to minimize both passenger and operating costs using a nonlinear integer programming program. The study found that by using random travel time, the optimal value is better than assuming the constant value [17]. In addition, travel time between any two successive bus stop is mostly determined by the corresponding road traffic conditions [18]. Sun et al. (2008) proposed dividing paths among bus stops to reduce the inadequacy of the bus schedule. Further, they tested three different stop skipping patterns including: normal scheduling (stop in all stations), zone scheduling (stop only in end of zone node), and express scheduling (stop in first, middle and end node of bus route). They examined different frequencies with assuming equal bus headway for these three types of scheduling. They found that higher traffic volumes cause decreased frequency, increased headway, and reduced travel cost [3]. Li et al. (1991) investigated the real-time scheduling problem for stop-skipping strategy by formulating a binary stochastic programming model. Within their study, they considered both schedule unconventionality and unsatisfied passenger demand [19]. Fu et al. (2003) also studied the stop skipping problem. In their approach, the stop skipping problem was simplified and they provided a minimum level of service for passengers waiting at skipped stations with considering equal bus headway. They found that if one bus skipped stations, the next following bus should have

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layover on that skipped stations for avoiding of increasing of passengers cost [20].

Literature gaps of the previous studies are as follows: Firstly, delay time penalty value is not considered in the optimization model formulation. Secondly, bus headway planning is considered with equal intervals in which the arrival rate patterns are not measured in the planning. Thirdly, certain stops in bus stop-skipping scheme are rationally assumed to be a random point or zonal stop pattern. In truth, demand pattern, arrival rate and bus headway have influences in stops selection [21, 22]. Nevertheless, these assumptions have a tremendous impact on bus operation performance and subsequently on delay time and running time in point of passenger's view and the fleet size in point of bus authorities view. However to obtain the best formulation for bus stop-skipping models these assumptions should be considered, which are taken into account in this paper.

The contribution of this study is to cover the literature gaps to selection of certain stops and bus headway pattern in bus stopskipping scheme. For this reason, passengers waiting time at the station and bus headway were balanced according to the arrival rate pattern and O-D matrix. Ultimately, fleet size will be considered as a fixed value. The first two considerations are proposed to discover the passengers cost and the last one is embraced to realize the total operating cost of the bus authority. Bus stop-skipping scheme should be considered in both of bus passenger and authority satisfaction. Thus, after the formulation of the above addressed the problem, an optimization model is proposed with the objective of minimizing the weighted sum of total in-station passenger delay, in-bus passenger delay and fleet size. The bus stop-skipping decision along with the bus route is reflected by a binary variable (0, 1). Thus, the proposed optimization model is a nonlinear integer programming.

The objective function presented in this paper is NP-hard (nondeterministic polynomial-time hard) and solutions out there to two powers of n which is the total number of bus bays. Therefore, it is problematical to find a precise method to solve this model. Hence, a genetic algorithm is suitable tools to solve the NP-hard optimization problem [17, 23]. Genetic algorithms (GAs) have some superiority

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for minimization of highly bumpy cost functions in comparing with other optimization tools such as: as long as no needed to have information that is based on other sources during the processing, GA performs well in combination with non-differentiable cost functions [24]. Furthermore, GA is randomized search methods, thus it has a better chance to explore the intact design space and reach the global optimum [25]. The population which is number of stop-skipping updated by mutation (criteria stop selection), crossover (random number of binary variables) and stop test (predetermined generation size).

Proposed optimization model Problem description and assumption

This study focuses on bus stop-skipping optimization in a certain stop-skipping, which examines the stop-skipping effect to minimize the objective function. First, the following assumptions are given: (a) to involve the arrival rate and passenger demand on the service pattern, bus headway is planned with un-equal interval. (b) Chosen certain stops in bus stop-skipping scheme is considered by the interaction of origin-destination matrix pattern and recommended bus stop spacing. (c) Buses capacity is considered as criteria in stop selection in bus stop-skipping. In other words, it is assumed that all passengers on each bus stop able to boarding to the bus. This assumption, however, has increased the challenge of figuring out bus stop-skipping optimization. The Schematic of frequency and headway of bus operation are shown in Figure 1.

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operation

Symbol definition

Considering a robustly connected bus network, the target bus line, denoted by m, is operating between bus stops, denoted by n, on this network. For the sake of presentation in the study, the key variables are defined as follows:

i Bus line l number i = 1, 2, ..., m

j Bus stop of bus line i, j = 1,2, ..., n, n + 1

 $P_{i,j}^{l}$ The number of passengers waiting on bus line l number i at stop j

 $P_{i-1,j}^{l}$ Total number of passengers remaining from a bus line l number i - 1 at bus stop j and waiting for bus number i

 $\omega_{i,j}$ Stop-skipping decision which is a binary variable "0-1", $\omega_{i,j} = (1; \text{ when bus line l number i stops at station j})$

0; otherwise

 $DT_{i,j}^{z}$ Departure time bus number i at bus stop j in the operation cycle

DW_{i,j} Dwell time bus number i at bus stop j

H_{i,j} bus headway number i at station j where

B_{i,j} The number of passengers boarding bus number i at stop j

 $B_{i,j}^*$ The number of boarding passengers remaining from bus number i - 1 at bus j

A_{i,j} The number of passenger alighting bus number i at stop j

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A^{*}_{i,j} The number of alighting passengers remaining from bus number i - 1 at bus j $T_{i,i}$ Travel time between two successive station i and i -1 $RT_{i,i}$ Runing time between two successive station i and i – 1 α Coefficient time for the average boarding one passenger β Coefficient time for the average alighting one passenger c Number of bus channels i D_i Distance between bus stop 1 to j $\overline{V}_{i,j}$ Bus travel speeds i σ_i Variance of running time bus line i, $\sigma_i = m. RT_{i,i}$, m is the coefficient of variance $\rho_{i,j}$ Deceleration time $\tau_{i,j}$ Acceleration time $AT_{i,j}^{P}$ Planning arrival time of bus line i at stop j $AT_{i,j}^{z}$ Actual arrival time of bus line i at stop j in the operation cycle z D_{i,j} Delay time bus number i at station j

 R_i Recovery time bus number i at the depot where $0 \le R_i < R_{max}$

Arrival time formulation

The arrival time of bus line l number i at stop j, $AT_{i,j}^{l}$, is equal by the total sum of departure time bus number i at station i - 1, $DT_{i,j}$, plus by the dwell time bus number i at station j - 1, $DW_{i,j}$, plus by travel time between two successive station i and i - 1, $T_{i,j}$, plus by coefficient parameters for running time variance, σ_j , deceleration, $\rho_{i,j}$, and acceleration, $\tau_{i,j}$. The stop-skipping decision is defined by as a binary variable in the arrival time formula, $\omega_{i,j}$, and if bus have a stop at station i the value of $\omega_{i,j}$ is equal by 1 and $\omega_{i,j}$ is equal by 0 otherwise. $AT_{i,j}^{l}$ is given by:

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$$AT_{i,j}^{l} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(DT_{i,j-1} + max \{ \alpha. [B_{i,j-1} + B_{i-1,j-1}^{*}.\omega_{i,j-1})] / c + \beta. [A_{i,j-1} + A_{i-1,j-1}^{*}.\omega_{i,j})] / c \} + \frac{D_{j}}{V_{i,j}} + \sigma_{j} + (\rho_{i,j} + \tau_{i,j} + \rho_{i,j-1}).\omega_{i,j} \right)$$

Minimizing the total in-station passenger delay time (f₁)

In the situation where binary variable $\omega_{i,j}$ of bus number i at station j is equal by 0, passenger remaining from bus number i should be waiting for the next arrival bus number i + 1 which in this case their average waiting time will be equal by three half bus headway, H_{i,j}, $\binom{1}{2}$ bus headway number i and 1 bus headway number i + 1). In the meantime, the new arrival passengers will be added to the passenger remaining from bus number i which their average waiting time is equal by half bus headway i + 1. Bus headway number i at station j is equal by the gap between the departure time bus number i at station j-1 and arrival time bus number i at station j. A passenger waiting time is impressed by bus headway and bus delay time. With minimized bus headway times and delay time, passenger waiting time at the station subsequently decreases. Delay time bus number i at station j, $D_{i,j}$ is equal by the difference between actual arrival time and planning arrival time. $D_{i,j}$ will be considered as a delay time penalty value in the bus stop-skipping formulation. $D_{i,i}$ is given by:

$$D_{i,j} = AT_{i,j} - AT_{i,j}^P$$

The total in-station passenger delay time included both new arrival, $B_{i,j}$, and passengers remaining from bus number i - 1, $B_{i-1,j}^*$, can be expressed as:

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$$f_1 = s_1 \cdot \sum_{i=1}^{m} \sum_{j=2}^{n} \left\{ \left(B_{i,j} \cdot H_{i,j} + B_{i-1,j}^* \cdot \left(3H_{i,j} + H_{i-1,j} \right) \right) / 2 + D_{i,j} \right\}$$

 s_1 is the weight of the in-station passenger delay time function f_1 .

Minimizing the total in-bus passenger delay time (f₂)

Running time, $R_{i,j}$, is equal by the difference between arrival time and departure time of bus i at stop j. $R_{i,j}$ is given by:

$$R_{i,j} = AT_{i,j} - DT_{i,j}$$

The total in-bus passenger delay time is equal by summing of running time between two consecutive station, $R_{i,j}$, plus dwell time at bus station j, $DW_{i,j}$, plus by coefficient parameters for deceleration, $\rho_{i,j}$, and acceleration, $\tau_{i,i}$.

$$\begin{split} f_2 &= s_2 . \sum_{i=1}^m \sum_{j=2}^n \big[(B_{i,j} - A_{i,j}) + (A_{i,j} - A_{i,j}^*) . \, \omega_{i,j} \big] \big\{ \big(AT_{i,j} - DT_{i,j} \big) \\ &+ \big(DW_{i,i} + \rho_{i,i} + \tau_{i,i} \big) . \, \omega_{i,i} + D_{i,i} \big\} \end{split}$$

The value of first brackets is equal by total passengers included new arrival passenger and passengers remaining from bus number i - 1 in-bus which is vary station by station. s_2 is the weight of in-bus passenger delay time function f_2 .

Minimizing the fleet size (f₃)

If the gap between arrival time bus number i at last station n and departure time bus number i at first station (n = 1) in the next operating cycle (total trip time) plus rest time at the depot is greater than 0 value bus operators are forced to add more buses to the pre fleet size to avoid the headway irregularity.

$$\left\{AT_{i,n}^{z} - DT_{i,1}^{z+1} + R_{i} \mid 0 \le R_{i} < R_{max}\right\} > 0$$

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The total trip time of bus number i is given by:

 s_3 is the weight of the fleet size function f_3 .

Objective function

The objective function consists of the three objectives that are covered in this paper including minimizing the total in-station passenger delay, f_1 , minimizing the total in-bus passenger delay, f_2 , and minimizing of the fleet size, f_3 .

$$\begin{split} \min Z &= f_1 + f_2 + f_3 \\ \min Z &= s_1 \cdot \sum_{i=1}^m \sum_{j=2}^n \left\{ \left(B_{i,j} \cdot H_{i,j} + B_{i-1,j}^* \cdot \left(3H_{i,j} + H_{i-1,j} \right) \right) / 2 + D_{i,j} \right\} \\ &+ s_2 \cdot \sum_{i=1}^m \sum_{j=2}^n \left[(B_{i,j} - A_{i,j}) + (A_{i,j} - A_{i,j}^*) \cdot \omega_{i,j} \right] \left\{ \left(AT_{i,j} - DT_{i,j} \right) \\ &+ \left(DW_{i,j} + \rho_{i,j} + \tau_{i,j} \right) \cdot \omega_{i,j} + D_{i,j} \right\} \\ &+ s_3 \cdot \sum_{i=1}^m \sum_{j=2}^n \left\{ \left(AT_{i,j} - DT_{i,j} \right) \\ &+ \left(DW_{i,j} + \rho_{i,j} + \tau_{i,j} \right) \cdot \omega_{i,j} + D_{i,j} - DT_{i,1}^{z+1} + R_i \right\} \end{split}$$

Constraints

The constraints for objective function are as follows: first, last, and transfer stations are not allowed to be skipped. Bus headways for both stop-skipping planed and non-stop skipping planed always should be between the maximum and minimum planed value to avoid the

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bunching and overtaking occurrence ($H_{min} \le H_{i,j} \le H_{max}$). The last bus arrival at last station plus recovery time is defined to the departure time in the first station on the new bus motion. The headway of first vehicle is equal by 0. Stop or non-stop need consider the factors including passenger OD pattern, arrival rate, and the land use comprehensively.

Genetic algorithm based solutions

The minimization models including three objective functions are nondeterministic polynomial optimization problem and complicated to be solved by any faithful algorithm. The number of stop-skipping patterns is equal by 2^n which is very large amount for a check-up. Thus, a genetic algorithm was used to solve the optimization problem [23]. Genetic algorithms, which have been originally introduced by John Holland (1975) is a gradient-free, stochastic-based optimization method that uses the idea of survival of the fittest and natural selection. The genetic algorithm concept is based on genetic evolution, where the fittest model has an upper probability of survival and reproduction, while lower-fitness values have lesser probabilities. The genetic algorithm based optimization solution was built with a MATLAB 2012a.

Parameter choice and initialization

Stage 1: (coding) determines coding and code length steps are the main point in the model solution structure. The bus headway interval will be used to length coding part which maximum headway (H_{max}) is upper bound and minimum headway (H_{min}) is lower bound. To encode the bus stop-skipping pattern, the length of the stop-skipping pattern is the number of stops skipped where 00 is represented as non-stop skipped pattern, 01 and 10 are represented the stop-skipping based on passenger volume and recommended bus stop spacing, respectively. Furthermore, passengers remaining at the bus stop and arrival rate should be coded which they will be used to detect the fitness value.

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Stage 2: (initial population) the initial population size will be determined by N chromosomes. Next step is to use phony random numbers as the primary resolution among N population.

Stage 3: (parameter choice) defines the crossing and mutation rate. The number of generations will be defined by k_i . According to Refs. [25, 26] and other relevant parameters of genetic algorithm, the value of crossover rate is 0.8 and the mutation rate is 0.005. The population and generation size of the GA are set to be 100 and 60 respectively.

Fitness value: The objective function presented in this paper is combined from three values (passenger costs and operation cost) which aims are to minimize these values. s_1 , s_2 and s_3 are the coefficients of the objective function. L value is defined by the syntax of coefficients which is large enough constant. The fitness function is equal by product of L by objective function.

Genetic operator

Stage 1: (selection) selection is to determine which individuals enter the next generation, for which roulette gambling law is chosen [23]. **Stage 2: (crossover)** in this stage the new chromosome will be generated by composition of two produced chromosome. Crossover probability is selected as a big number in the range of [0, 1]. To generate two new chromosomes, this value in the next generation k_i

should be replaced by an integer number between 1 and N. **Stage 3: (mutation)** mutation rate is a smaller number in the range of [0, 1]. In the case of chromosome's random number was bigger than mutation rate the value of gen should be change from 0 to 1, vice versa.

Stopping criteria: The substitution of poor quality solutions with new solutions is based on some fixed strategies. k_{max} will be defined as termination criterion. If $k > k_{max}$, operation cycle are stopped and prints the optimal value (best chromosome of the last generation).

Repeating: If $k < k_{max}$, then k = k + 1 and evaluation, optimization and replacement of solutions are repeated until the termination criterion is met.

Application to a real case

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To apply the genetic evolutionary model to a real case study optimization problem encoding the potential solutions and defining the objective function to be optimized must be addressed. A case study based on an actual public bus operation in Halifax, Canada (Figure 2) is used to demonstrate the usefulness of stop-skipping scheme in an optimization bus travel time.



Figure 2 Case study

The total number of passenger transfers with this line is 4,482 per day. The bus line to be studied in this paper is about 26,851 km from northeast to south where the transfer of passengers from suburban areas in the city centre takes place. It has 85 bus stops where the origin and destination line terminals are used for parking buses and crews' rest breaks, and for boarding and alighting passengers. Each bus has 31 seats and the total capacity is 49 people. The studied period is 1 hour during the rush traffic period in the morning. The acceleration and deceleration time is 10 s. Passengers volume is shown in Figure 3. Passenger waiting endurance time is considered as 30 min. Delay time penalty value is considered as 10 min. Coefficient of travel time is set as 0.15. The Un-equal headway pattern is tabulated in Table 1 which it is provided according to volume passenger pattern and actual average arrival rate.

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Headway (min)	Frequency	Service											
5	12	5	7	6	5.5	4	3.5	4	6	6	6	5	5
6	10	6	8	6	4	6	4	6	5	7	8		
7	9	10	4	7	4	5	4	8	8	10			
8	8	10	8	7.5	6.5	5.5	8	6.5	8				
9	7	10	8	6.5	6.5	9	11	11					
10	6	12	8	8	12	8	12						
13	5	15	10	8	12	15							
15	4	20	20	10	20								
21	3	15	30	15									
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Table 1 Un-equal headway pattern

Figure 3 Passengers volume at different bus stops Result analysis

The genetic algorithm parameters, passenger volume and objective function are coded in MATLAB R2012a and the tests were performed on a personal computer with Inter(R) Core(TM) i5-2400 CPU @3.10 GHz, and 8.00 G RAM in the environment of Microsoft Windows 7 professional. Calculation results of the numerical example are shown in Table 2. In Table 2, 00 corresponds to bus service with non-stop skipping pattern, 01 and 10 corresponds to bus service with stops skipping pattern according to passenger volume and recommended stop spacing analysis.

Table 2 Different service pattern along with different bus headway

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Headway (min)	Frequency	Service pattern												Objective values	Saving cost (%)
5	12	01	01	10	00	10	00	01	01	10	01	10	00	35560	16.89%
		00	00	00	00	00	00	00	00	00	00	00	00	42785	
6	10	00	10	01	01	01	10	00	00	10	10			38910	14.81%
		00	00	00	00	00	00	00	00	00	00			45673	
7	9	10	10	10	00	00	01	01	00	10				41820	16.24%
		00	00	00	00	00	00	00	00	00				49930	
8	8	00	10	01	00	10	01	00	10					46235	4.71%
		00	00	00	00	00	00	00	00					48520	
9	7	10	10	00	01	01	10	00						48108	21.83%
		00	00	00	00	00	00	00						61543	
10	6	01	00	10	10	00	01							51098	29.95%
		00	00	00	00	00	00							72940	
13	5	10	00	01	10	00								55870	19.88%
		00	00	00	00	00								69732	
15	4	00	10	00	01									56934	7.02%
		00	00	00	00									61233	
21	3	00	10	00										59543	6.36%
		00	00	00										63589	
30	2	00	01											61043	4.53%
		00	00											63941	

From the result, it shows that the minimal and the maximal value of optimized objective function are 61043 and 51098, respectively. Compared with non-stop skipping pattern (72940 and 63941), the total cost is reduced by 29.95% and 4.53%, respectively which this proves that optimization is very considerable and significant. The service patterns presented in this paper are reasonable to save system cost deeply. Furthermore, increased headway results in a greater optimized objective function. Therefore, with increased bus frequency, passenger waiting time at the bus stop and whole system costs subsequently decreases.

Conclusions

In this paper, optimization of passenger and operating costs through using genetic algorithm based method has been presented. The objective function is developed by minimizing the total delay at station, travel time in-bus and fleet size. The maximum and minimum results obtained by numerical example can be saved by 29.95% and 4.53%, respectively, compared with the un-optimized value. The obtained optimization results show that the proposed service pattern with un-equal headway is reasonable. Forthcoming work should discuss about preparation different service pattern according to traffic volume and bus speed limitation.

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Acknowledgments

This research is funded by Canadian Foundation for Innovation (CFI) and the Province of Nova Scotia. The authors thank the Metro Transit, Halifax Regional Municipality for providing the test data used in this study. The authors also would like to thank Mr. Levi Megenbir for proof reading the article.

References

- Dessouky, M., et al., *Real-time control of buses for schedule coordination at a terminal*. Transportation Research Part A: Policy and Practice, 2003. 37(2): p. 145-164.
- Wagale, M., et al., *Real-time Optimal Bus Scheduling for a City Using A DTR* Model. Procedia - Social and Behavioral Sciences, 2013. 104(0): p. 845-854.
- Sun, C., W. Zhou, and Y. Wang, Scheduling Combination and Headway Optimization of Bus Rapid Transit. Journal of Transportation Systems Engineering and Information Technology, 2008. 8(5): p. 61-67.
- Estrada, M., et al., Design and implementation of efficient transit networks: Procedure, case study and validity test. Transportation Research Part A: Policy and Practice, 2011. 45(9): p. 935-950.
- Karlaftis, M.G., A DEA approach for evaluating the efficiency and effectiveness of urban transit systems. European Journal of Operational Research, 2004. 152(2): p. 354-364.
- Li, Y., W. Xu, and S. He, Expected value model for optimizing the multiple bus headways. Applied Mathematics and Computation, 2013. 219(11): p. 5849-5861.
- 7. Wu, J. and N. Hounsell, *Bus Priority Using pre-signals*. Transportation Research Part A: Policy and Practice, 1998. 32(8): p. 563-583.
- Wahlstedt, J., Impacts of Bus Priority in Coordinated Traffic Signals. Procedia -Social and Behavioral Sciences, 2011. 16(0): p. 578-587.
- Fu, L. and X. Yang, Design and Implementation of Bus-Holding Control Strategies with Real-Time Information. Transportation Research Record: Journal of the Transportation Research Board, 2002. 1791(-1): p. 6-12.
- Xuan, Y., J. Argote, and C.F. Daganzo, *Dynamic bus holding strategies for schedule reliability: Optimal linear control and performance analysis.* Transportation Research Part B: Methodological, 2011. 45(10): p. 1831-1845.
- Chen, X., et al., Analyzing urban bus service reliability at the stop, route, and network levels. Transportation Research Part A: Policy and Practice, 2009. 43(8): p. 722-734.
- Fu, L. and X. Yang, *Design and implementation of bus-holding control strategies* with real-time information. Transportation Research Record: Journal of the Transportation Research Board, 2002. 1791(1): p. 6-12.

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- 13. Furth, P.G., Alternating deadheading in bus route operations. Transportation science, 1985. 19(1): p. 13-28.
- Delle Site, P. and F. Filippi, Service optimization for bus corridors with short-turn strategies and variable vehicle size. Transportation Research Part A: Policy and Practice, 1998. 32(1): p. 19-38.
- 15. Li, Y., J.-M. Rousseau, and F. Wu, *Real-Time Scheduling on a Transit Bus Route*. 1991.
- Sun, A. and M. Hickman, *The Real–Time Stop–Skipping Problem*. Journal of Intelligent Transportation Systems, 2005. 9(2): p. 91-109.
- 17. Liu, Z., et al., *Bus stop-skipping scheme with random travel time*. Transportation Research Part C: Emerging Technologies, 2013. 35(0): p. 46-56.
- 18. Yan, Y., et al., Robust optimization model of schedule design for a fixed bus route. Transportation Research Part C: Emerging Technologies, 2012. 25(0): p. 113-121.
- Li, Y., R. J.-M., and M. Gendreau, *Real-time scheduling on a transit bus route: a* 0–1 stochastic programming model, in *Proceedings of the Thirty-Third Annual Meeting*. 1991, Transportation Research Forum. p. 157-166.
- Fu, L., Q. Liu, and P. Calamai, *Real-time optimization model for dynamic scheduling of transit operations*. Transportation Research Record: Journal of the Transportation Research Board, 2003. 1857(1): p. 48-55.
- 21. Kim, M. and P. Schonfeld, *Integrating bus services with mixed fleets*. Transportation Research Part B: Methodological, 2013. 55(0): p. 227-244.
- 22. Hill, S.A., *Numerical analysis of a time-headway bus route model*. Physica A: Statistical Mechanics and its Applications, 2003. 328(1–2): p. 261-273.
- Liang, F. and W. Hung Wong, Evolutionary Monte Carlo: Applications to Cp Model Sampling and Change Point Problem. Statistica Sinica, 2000. 10: p. 317-342.
- 24. Yu, B., et al., *Parallel genetic algorithm in bus route headway optimization*. Applied Soft Computing, 2011. 11(8): p. 5081-5091.
- 25. Khosravi, A., et al., A genetic algorithm-based method for improving quality of travel time prediction intervals. Transportation Research Part C: Emerging Technologies, 2011. 19(6): p. 1364-1376.
- Dias, T.G., J.P.d. Sousa, and J.F. Cunha, *Genetic Algorithms for the Bus Driver* Scheduling Problem: A Case Study. The Journal of the Operational Research Society, 2002. 53(3): p. 324-335.

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