Optimization Analysis of Bus Scheduling

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Abstract

Taking the bus scheduling challenges in City GY as a case study, this paper explores the rational dispatching of public transportation systems with dual objectives: fulfilling operational requirements while maximizing transport company benefits. Through statistical analysis of collected survey data and systematic integration of optimization theory, we develop computational solutions via programming implementation, ultimately deriving an optimal scheduling framework. The methodology demonstrates extensibility and can be generalized to address analogous scheduling problems across transportation domains.

Keywords

Bus Scheduling; Optimization; The Mathematical Model.

1. Introduction

With the significant improvement of social living standards, the number of transportation vehicles, especially private cars, has increased rapidly, leading to increasing road traffic pressure. How to ensure appropriate comfort for travelers while satisfying the green travel demand of most people is a major challenge that needs to be addressed. As an effective solution to this problem, the development and improvement of public transportation are major issues that need to be considered first. Among them, the reasonable scheduling of buses is of paramount importance. In reality, during the morning and evening peak hours, passengers often complain about overcrowding on buses and serious delays in bus arrivals. Therefore, higher service standards are required for buses, with passengers demanding safer, more convenient, comfortable, and faster services. This in turn raises the practical issue of the need for more rational and optimized bus scheduling. At the same time, bus companies also need to maximize their profits while meeting the normal travel needs of passengers. How to reasonably determine the number of buses on a fixed bus route and arrange a departure schedule to meet passenger travel demand, increase passenger satisfaction, and take into account company interests have obviously become focal points that need to be addressed[1].

Currently, for this research topic, both domestic and foreign studies on non-intelligent bus operation modes still rely heavily on computer programming to analyze data and optimize scheduling for specific bus routes using optimization theory. For intelligent bus operation modes, genetic algorithms and fuzzy neural networks are often used for reasonable bus control and scheduling, along with simulation technology to analyze the reliability of scheduling schemes. Of course, the development of intelligent bus scheduling systems is the general trend. However, due to the current state of development in China, the full development and popularization of intelligent bus scheduling systems will still take a considerable amount of time[2-4]. Therefore, for practical problems currently arising in bus operations, we will first adopt traditional models for reasonable scheduling to resolve these issues.

Taking the No. 8 bus route in GY City as an example, this paper analyzes the collected survey data, uses computer programming, and employs MATLAB software to find the optimal solution, ultimately

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obtaining an optimized scheduling scheme for this bus route to solve the practical problems existing in its operation.

2. Problem Description

The No. 8 bus route in GY City has stations in both the upstream and downstream directions station names $A_i\left(i=0,1,\cdots,15\right)$ (specific station names are provided in Appendix 1). Table 1 lists the passenger boarding and alighting statistics at each station in both directions during a working day. The total mileage of this bus route is 14.4 kilometers. The buses assigned to this route by the GY City Bus Company each have a loading capacity of 25 passengers. Statistical data indicates that the average speed of buses on this route is 20 km/h. Currently, there are many problems on this route, such as buses not arriving on time, excessive waiting times for passengers, and high passenger load factors. It is now required to design an optimized scheduling scheme, including a schedule and the number of required buses, so that passengers' waiting time at each station does not exceed 15 minutes, generally not more than 7 minutes during the morning peak hours, and the vehicle load rate does not exceed 130% or fall below 40%.

Table 1. Passenger Boarding and Alighting Statistics at Each Station in Both Directions During a Working Day

GY City Bus Route 8 Passenger Volume Statistics by Time Period and Station (Upbound Direction: A15 to A0)								
Station		A15	A14	A13	A12	A11	A10	A9
7:00-9:00	Board	264	113	50	19	10	37	22
	Alight	0	7	8	107	58	12	96
9:00-11:00	Board	183	73	62	34	30	49	29
	Alight	0	11	23	21	42	37	32
11:00-13:00	Board	135	102	56	43	65	37	53
	Alight	0	9	32	20	26	34	51
13:00-15:00	Board	134	82	72	47	49	57	21
	Alight	0	7	19	32	43	18	46
15:00-17:00	Board	127	73	63	43	39	42	37
	Alight	0	6	9	18	27	36	31
17:00-19:00	Board	141	61	28	37	19	27	43
	Alight	0	12	17	29	18	37	26

GY City Bus Route 8 Passenger Volume Statistics by Time Period and Station (Upbound Direction: A15 to A0)								
A8	A7	A6	A5	A4	A3	A2	A1	A0
38	127	21	34	42	28	43	42	0
89	132	13	22	53	33	102	97	52
42	58	39	46	29	34	11	12	0
18	62	47	38	53	62	49	73	166
37	69	36	48	57	43	29	21	0
22	71	29	39	92	89	73	126	137
27	59	42	37	39	28	6	9	0
32	35	73	61	52	41	54	63	127
29	36	46	32	31	42	29	7	0
27	19	47	63	74	64	89	77	97
41	32	27	43	37	29	41	43	0
43	52	19	27	13	26	87	104	142

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Table 2. Passenger Boarding and Alighting Statistics at Each Station in the Downbound Direction During a Workday

GY City Bus Route 8 Passenger Volume Statistics by Time Period and Station (Downbound Direction: A0 to A15)								
Station		A0	A1	A2	A3	A4	A5	A6
7:00-9:00	Board	157	68	39	47	59	87	26
	Alight	0	9	7	29	47	37	49
9:00-11:00	Board	83	62	51	49	57	62	71
	Alight	0	7	7	19	32	47	32
11:00-13:00	Board	55	47	43	52	39	45	43
	Alight	0	9	11	13	16	36	37
13:00-15:00	Board	47	51	35	29	42	35	39
	Alight	0	8	9	11	26	37	47
15:00-17:00	Board	57	64	51	53	42	53	63
	Alight	0	11	17	7	9	29	43
17:00-19:00	Board	16	23	37	53	33	42	53
	Alight	0	50	9	13	27	18	27
GY City Bus Route 8 Passenger Volume Statistics by Time Period and Station (Downbound Direction: A0 to A15)								
A7	A8	A9	A10	A11	A12	A13	A14	A15
39	87	92	103	27	63	7	8	0
152	37	62	73	27	57	62	163	77
42	37	35	36	29	41	52	29	0
62	52	37	29	53	47	89	102	93
29	37	53	54	47	43	52	29	0
29	38	42	39	42	62	71	102	113
42	53	41	29	24	35	47	9	0
48	39	52	39	46	67	53	41	31
47	44	35	28	51	42	47	19	0
36	49	57	55	63	71	78	95	67
59	142	28	29	53	77	13	11	0
42	35	23	123	28	12	57	55	103

3. Problem Analysis

The main factors affecting bus scheduling are buses, bus stops, and passengers. As can be seen from Table 1, the number of passengers during the morning peak hours (7:00-9:00) is significantly different from that in other time periods, so it can be analyzed separately. To balance the interests of the company and passenger satisfaction (meeting passenger waiting requirements), in the established scheduling scheme, passenger satisfaction indicators include waiting time and travel time (the time taken by passengers from boarding to alighting at their destination). Generally, passengers are not too

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concerned about travel time, so waiting time is the main indicator. The profit pursuit of bus companies requires using the minimum number of buses to complete scheduling requirements while satisfying passenger travel demand, with the empty load rate being as low as possible[5]. Therefore, the number of operating buses and the empty load rate can be used as profit indicators for bus companies.

4. Basic Assumptions of the Model

(1) During the morning peak hours, passengers arrive at bus stops within a short period of time. At other times, the number of passengers arriving at bus stops follows a uniform distribution.

(2) During peak hours, passengers consider the degree of crowding in the bus as a secondary factor.

(3) Buses operate on the specified route without interference from other factors, in good condition, and can arrive on time.

(4) Each bus stop is relatively independent of the others.

(5) For the convenience of scheduling, buses depart at the same time interval within the same time period.

(6) Buses travel at a constant speed of 20 km/h on this bus route, without considering vehicle startup, stopping, and other factors.

(7) The fare for the entire journey is the same for all passengers.

5. Symbol Explanation

(1) $E(k)$:Cumulative passenger count upon arrival at station k

(2) $E(k)$: Total boarding passengers at station k

(3) $F(k)$:Total alighting passengers at station k

(4) A :Operator's profit

(5) B :Operator's total revenue

(6) C_a :Total departures in upbound direction

(7) C_b :Total departures in downbound direction

(8) D :Fixed cost per vehicle dispatch

(9) E :Daily other fixed operational costs

(10) T_1 :Peak-hour departure interval (upbound)

(11) T_2 **:**Off-peak departure interval (upbound)

(12) T_3 :Low-demand departure interval (upbound)

(13) T_4 :Peak-hour departure interval (downbound)

(14) T_5 :Off-peak departure interval (downbound)

(15) T_6 :Low-demand departure interval (downbound)

(16) $Q(m,n)$:Passenger load on vehicle m arriving at station n

(17) $N_c(m,n)$:Boarding count on vehicle m at station n

(18) $N_d(m,n)$:Alighting count from vehicle m at station n

(19) r_{mn} :Waiting time satisfaction index

(20) S :In-vehicle crowding perception index

(21) G :Actual in-vehicle passenger count

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(22) w_{mn} :Time-period-specific crowding satisfaction

(23) $\alpha_i\left(i=1,2,3\right)$:Probability

6. Model Establishment and Solution

6.1 Data Statistics and Analysis

It follows directly from mathematical principles that $M(k)=\sum_{i=1}^{k}(E(i)-F(i))$ .Develop a MATLAB program to generate a statistical table (Table 3, Table 4) and a graphical chart (Figure 1) showing the cumulative passenger counts on buses arriving at k station during different time periods along the route.

Table 3. Cumulative Passenger Counts upon Arrival at k Station by Time Period

GY City Route 8 Bus Cumulative Passenger Counts (Upbound: A15 to A0)							
	A15	A14	A13	A12	A11	A10	A9
7:00-9:00	264	370	392	304	256	281	207
9:00-11:00	183	245	284	297	285	297	294
11:00-13:00	135	228	252	275	314	317	319
13:00-15:00	134	209	262	277	283	322	299
15:00-17:00	127	194	248	273	285	291	297
17:00-19:00	141	190	201	209	210	200	217

GY City Route 8 Bus Cumulative Passenger Counts (Upbound: A15 to A0)								
A8	A7	A6	A5	A4	A3	A2	A1	A0
156	151	159	171	162	157	98	43	-9
318	314	306	314	290	262	204	143	-23
334	332	339	348	344	298	254	149	-12
292	316	285	261	248	235	187	133	6
299	316	315	284	241	219	159	89	-8
215	195	203	219	243	246	200	139	-3

Table 4. Time-Specific Passenger Boarding and Alighting Statistics per Station in Downbound Direction

GY City Route 8 Bus Boarding and Alighting Passenger Counts (Downbound: A0 to A15)							
	A0	A1	A2	A3	A4	A5	A6
7:00-9:00	157	216	248	266	278	328	305
9:00-11:00	83	138	182	212	237	252	291
11:00-13:00	55	93	125	164	187	196	202
13:00-15:00	47	90	116	134	150	148	140
15:00-17:00	57	110	144	190	223	247	267
17:00-19:00	76	49	77	107	123	147	173

GY City Route 8 Bus Boarding and Alighting Passenger Counts (Downbound: A0 to A15)								
A7	A8	A9	A10	A11	A12	A13	A14	A15
192	242	272	303	303	297	217	60	-17
271	256	254	247	223	217	180	107	14
202	201	190	215	220	201	192	119	6
132	146	137	127	105	73	66	34	3
278	273	251	224	212	183	152	76	9
188	295	300	206	231	296	252	108	5

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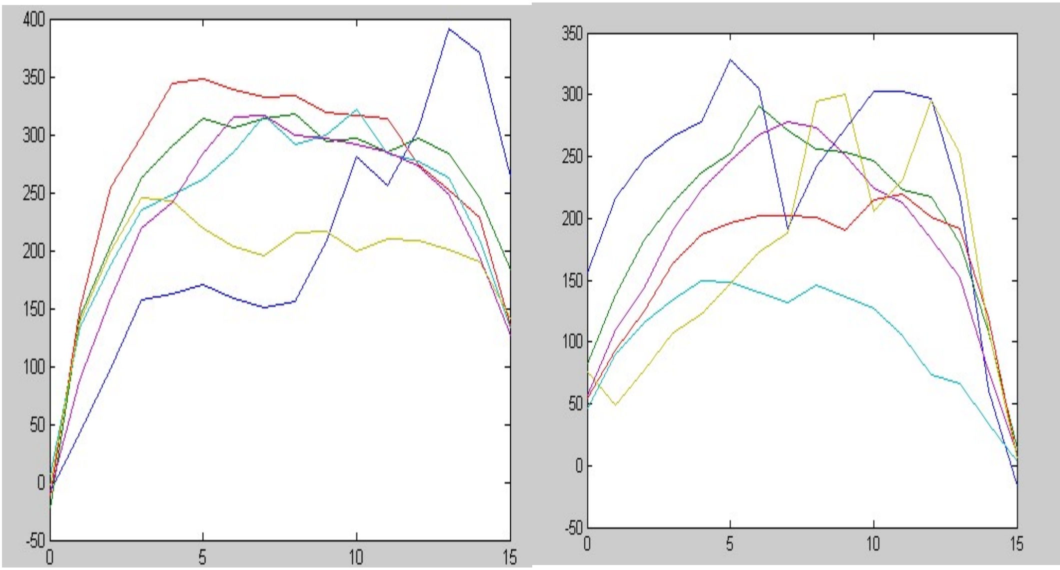

Figure 1. Cumulative Passenger Counts by Time Period upon Arrival at k Station

We first approximate the required number of vehicles as a reference for model validation. From the statistical charts, excluding the special period 7:00-9:00, the maximum passenger load in the upbound direction (A15 to A0) occurs between Station $A7$ and Station $A8$, with peak values at these stations. Clearly, if the vehicle capacity meets passenger demand between Stations $A7$ and $A8$, it will suffice for the entire route during that period.Therefore, during the 7:00-9:00 period, the average cumulative passenger count at Stations $A1$ and $A2$ is used, while for other time periods, the average cumulative passenger count at Stations $A7$ and $A8$ is adopted.From this analysis, the approximate maximum total passenger load across all time periods on the upbound route is determined to be $(392+370+318+314+334+332+292+316+299+316+215+195)/2=1846.5$, it means 1847 passengers.A similar analysis applies to the downbound route. Excluding the special period 17:00-19:00, the maximum passenger load occurs between adjacent Stations $A5$ and $A6$. For 17:00-19:00, the average cumulative passenger count at Stations $A12$ and $A13$ is used.Thus, the approximate maximum total passenger load across all time periods on the downbound route (up to Station $M(k)$) is $(328+305+252+291+196+202+148+140+247+246+292+252)/2=1451.5$,it means 1452 passengers.Combining both routes, the total approximate maximum passenger load is $1452+1847=3299$ .Assuming a bus capacity 130%, the minimum required departures T is 102 trips. If the bus capacity 40%, the minimum required departures become $3299/(25*40\%)=329.9$, it means 330 trips.The total route length is 14.4 kilometers, and statistical data shows an average operating speed of 20 km/h. Therefore, the one-way travel time from the starting station to the terminal is $t=s/v=14.4/20=0.72$ hour (43.2 minutes).Given a daily total operating time of 12 hours, each vehicle can complete a maximum of 16 ($12/0.72=16.66$) cycles per day.Hence, the minimum number of vehicles required is 7 ($102/16=6.375$), and the maximum number is 21 ($330/16=20.625$).

In summary, the number of buses required for this route should range between 7 and 21 vehicles. This estimation, however, is based on idealized assumptions-specifically, that the number of vehicles dispatched daily from both the upbound and downbound stations is identical. If practical factors (e.g., asymmetric vehicle allocation for upbound/downbound directions, maintenance downtime, or traffic delays) are incorporated, the actual vehicle requirement may exceed 21.

The above analysis provides only a rough estimation of the required vehicle range, serving as a reference basis for the solution data of our established model.To ensure that our model more

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accurately reflects real-world conditions and to simplify problem-solving, we first categorize the 12 statistically observed time periods into peak periods, steady periods, and off-peak periods.

In real-world operations, passenger demand and corporate profitability must be balanced simultaneously, yet achieving simultaneous optimality for both parties is inherently impossible. Therefore, a pragmatic approach is to formulate corporate profit as the objective function while treating passenger service requirements (i.e., passenger interests) as operational constraints.

Let A represent corporate interests,so

$$A = B - \left(C_a - C_b\right) * D - E,$$

$$C_a = \frac{1\times 60}{T_1} + \frac{4\times 60}{T_2} + \frac{1\times 60}{T_3}$$

$$C_b = \frac{1\times 60}{T_4} + \frac{3\times 60}{T_5} + \frac{2\times 60}{T_6}$$

Passenger waiting time is regarded as a passenger benefit metric.However, waiting time is a stochastic variable that cannot be deterministically bounded above or below a fixed threshold.Therefore, it is appropriate to characterize actual passenger benefits via probabilistic distribution functions.This leads to the following mathematical model.

6.2 Model One

$$\max(A) = B - (C_a - C_b) * D - E,$$

$$\text{st. } p\{t > 15\} < \alpha_1$$

$$P\{G(m,n) + N_c(m,n) - N_d(m,n) > 32\} < a_2$$

$$P\{G(m,n) + N_c(m,n) - N_d(m,n) < 10\} < a_3$$

Or

$$\text{st. } p\{t > 75\} < \alpha_1$$

$$P\{G(m,n) + N_c(m,n) - N_d(m,n) > 32\} < a_2$$

$$P\{G(m,n) + N_c(m,n) - N_d(m,n) < 10\} < a_3$$

For this model, constructing an explicit functional representation of the constraint proves highly non-trivial, thereby introducing significant computational complexity in practical implementation. However, analytical insights reveal that dispatch frequency dominates the operational profitability of transit agencies, making its optimization the central challenge in resolving this trade-off.

The objective function analysis reveals that the optimal values of A (profit) and T (dispatch interval) are sensitive to temporal partitioning; thus, we adopt a 2-hour time window segmentation for model resolution.

Given the vehicle load factor ranges between 40% and 130% (where the bus has 25 seats), the effective passenger capacity per trip must satisfy 10 ≤Actual passenger capacity≤32. To ensure the bus transports all passengers arriving at stops within each time window while adhering to the occupancy constraints, the following optimization model is formulated.

6.3 Model Two

$$d_{mn} = \begin{cases} \frac{h_{mn}}{32}, \frac{h_{mn}}{32} \in Z^{+} \\ [\frac{h_{mn}}{32}]+1, \frac{h_{mn}}{32} \notin Z^{+} \end{cases}$$

$$D = \sum_{m=1}^{2} \sum_{n=1}^{6} d_{mn}$$

h_{mn} represents the maximum number of passengers on the bus when it arrives at station n during each uplink and downlink time period.

By calculation, a statistical table of the number of trips to meet scheduling demands during each time period can be obtained (Table 5).

Table 5. Bus Departure Frequency by Time Period

	7:00-9:00	9:00-11:00	11:00-13:00	13:00-15:00	15:00-17:00	17:00-19:00
Upbound Route	13	10	11	10	10	8
Downbound Route	11	9	7	5	9	10

The formula derivation demonstrates that the total number of departures required during the workday is 62 + 51 = 113. To schedule dispatch intervals, divide the duration of each time window (120 minutes) by the corresponding number of departures in that window, yielding the average dispatch interval for each period

$$t_{mn} = 120/d_{mn}$$

Table 6. Bus Departure Frequency by Time Period

	7:00-9:00	9:00-11:00	11:00-13:00	13:00-15:00	15:00-17:00	17:00-19:00
Upbound Route	9.2	12	10.9	12	12	15
Downbound Route	10	13.3	17.1	24	13.3	12

The table contains decimal values. However, in practice, all operational stations use minutes as the smallest scheduling unit for dispatch timetables. Thus, time intervals must be rounded to integers.Similarly, two scenarios are analyzed.Case 1 (Integer Interval): If the time interval t_{mn} is an integer, use t_{mn} directly as the dispatch interval.Implementation: Schedule d_{mn} departures at equidistant intervals over the time window.Case 2 (Decimal Interval): If the interval tt is a decimal, let $P[t_{mn}]$ and $Q[t_{mn}]$ be the two consecutive integers adjacent to t_{mn}, such that:

$$P[t_{mn}] \le t_{mn} \le Q[t_{mn}]$$

Modeling

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$$\begin{cases} u_{mn} + v_{mn} = d_{mn} \\ P[t_{mn}] * u_{mn} + Q[t_{mn}] * v_{mn} = 120 \end{cases} m = 1,2; n = 1,2,\cdots,6$$

Through the model calculations, we derive the dispatch frequency u_{mn} with interval $P[t_{mn}]$ and vv with interval $Q[t_{mn}]$ .To balance dispatch density across stations, we rationally partition the time windows where $P[t_{mn}]$ and $Q[t_{mn}]$ are applied as intervals.

Based on the derived dispatch frequencies u_{mn} and v_{mn} , and their corresponding time intervals t_{mn} for each period, we calculate the specific dispatch counts. Practicality and cost-efficiency are prioritized. The number of vehicles assigned to a route within a single time window must balance operational feasibility (e.g., driver shifts, maintenance) and profitability.Using statistical data (Table 7), adjacent periods with identical intervals tt are merged to simplify scheduling and reduce operational complexity.Morning peak demand is addressed by refining the dispatch timetable and sequence (Table 8), ensuring alignment with passenger flow patterns.

Table 7. Statistical Results of Key Calculation Metrics for Both Operational Directions Across Time Periods

	Up Direction				Down Direction			
Time Period	Max. Passenger Capacity	Number of Dispatches	Avg. Load Factor	Dispatch Interval	Max. Passenger Capacity	Number of Dispatches	Avg. Load Factor	Dispatch Interval
7:00-9:00	392	13	30	9.2	328	11	26.9	10
9:00-11:00	318	10	32	12	291	9	32.3	16.3
11:00-13:00	334	11	30.3	10.9	202	7	28.9	17.1
13:00-15:00	316	10	31.6	12	148	5	29.6	24
15:00-17:00	316	10	31.6	12	267	9	29.7	13.3
17:00-19:00	215	8	26.9	15	173	10	17.3	12

Table 8. Bus Dispatch Timetable

Up Direction			Down Direction		
Time Period	Dispatches	Interval (minutes)	Time Period	Dispatches	Interval (minutes)
7:00-7:49	7:1—7	7	7:00-7:49	7:1—7	7
7:49-8:55	6:8—13	11	7:49-8:54	5:8—12	13
8:55-10:55	10:14—23	12	8:54-11:00	9:13—21	14
10:55-12:56	11:24—34	12	11:00-13:00	8:22—29	15
12:56-14:56	10:35--44	12	13:00-15:00	8:30—37	15
14:56-16:56	10:45—54	12	15:00-16:24	6:38—43	14
16:56-18:00	8:55—62	8	16:24-17:00	3:44—46	13
18:00-19:00	4:63—66	15	17:00-18:03	9:47—55	7
*	*	*	18:03-19:03	6:56—61	10

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Analysis of the table reveals that passenger volumes in the down direction are significantly lower than those in the up direction, necessitating differentiated scheduling strategies.To minimize empty runs and enhance passenger comfort, we optimized the down-direction timetable through interval adjustments and passenger load balancing. The optimized dispatch timetable (Table 9) integrates these adjustments while preserving service reliability.

Table 9. Adjusted Bus Dispatch Timetable

Up Direction			Down Direction		
Time Period	Dispatches	Interval (minutes)	Time Period	Dispatches	Interval (minutes)
7:00-7:49	7:1—7	7	7:00-7:49	7:1—7	7
7:49-8:55	6:8—13	11	7:49-8:54	5:8—12	13
8:55-10:55	10:14—23	12	8:54-11:04	10:13—22	13
10:55-12:56	11:24—34	12	11:04-13:04	10:23—32	12
12:56-14:56	10:35--44	12	13:04-15:04	8:33—40	15
14:56-16:56	10:45—54	12	15:04-17:03	11:41—51	11
16:56-18:00	8:55—62	8	17:03-17-59	8:52—59	7
18:00-19:00	4:63—66	15	17:59-19:02	7:60—66	9

We now calculate the minimum fleet size required to operate the full-day timetable.

Buses arriving at terminals require dwell time for boarding/alighting. Terminals must maintain sufficient standby vehicles to ensure on-time departures per the timetable.The maximum vehicle deficit between up/down directions is 4, occurring during the final time window.Despite equal total daily departures (66 for both directions), the up direction operates at higher frequencies in most periods. This creates temporary vehicle surpluses at Terminal $A0$, ensuring down-direction schedule adherence. Morning peak demand dictates the upper bound for fleet sizing, as it requires the highest vehicle density.A fleet sized for morning peak requirements will sufficiently cover all other periods. With a 43.2-minute round-trip time and 7-minute peak intervals, a minimum of 14 vehicles (7 per direction) is required for simultaneous departures from $A15$ and $A0$.Factoring in a 4-vehicle deficit and operational buffers, the final fleet size is determined as 16 vehicles, aligning with empirical validation ranges[6-10].

We now calculate passenger satisfaction and operator profitability metrics to evaluate the transit system's performance.

As established, passenger satisfaction G depends on two factors: waiting time and in-vehicle crowding level. To integrate these factors, we assign a weighted parameter μ, yielding the following formula:

$$G = \mu * r_{mn} + (1-\mu) * s_{mn}$$

In this model, we assign a weighting coefficient μ = 0.5 to balance the dual objectives.

In our scheduling model, under the validity of the original assumptions (e.g., fixed headways and demand patterns), all passenger waiting times across time intervals strictly comply with operational targets. Therefore, the waiting time satisfaction score is assigned 100. The crowding satisfaction score is calculated as follows:

$$w_{mn} = \begin{cases} 100\% - \dfrac{G-25}{25}, G \geq 25 \\ 100\%,\ G < 25 \end{cases}$$

$$S = (\sum_{m=1}^{2}\sum_{n=1}^{6} w_{mn}) / 12$$

Based on the calculation, the passenger satisfaction score G is 95.195%.

Operator satisfaction is typically influenced by two factors: vehicle vacancy rate (empty-load rate) and fleet size. However, statistical analysis reveals that vacancy rates below 40% predominantly occur in the latter half of bus routes and with minimal frequency. Despite the negative impact of high vacancy rates on operational efficiency, the specificity of the surveyed data justifies simplifying Goperator to fleet size satisfaction. The formula is defined as:

$$P = Q = \frac{R-U}{R} * 100\%$$

Let P denote operator profitability satisfaction (linked to cost efficiency and revenue), Q represent fleet size satisfaction, R be the actual operational fleet size, and U indicate emergency reserve vehicles. Integrating passenger satisfaction and operator profitability , the results are derived as follows:

The passenger satisfaction score G is 95.195%.The operator profitability satisfaction is 87.5%.

Under the validated assumptions, the proposed scheduling scheme is operationally optimal.

7. Conclusion

The proposed model is developed under idealized assumptions, demonstrating high satisfaction levels for both passengers and operators , confirming its near-optimal performance.

Algorithmic computations and data visualizations are implemented via programmatic methods, ensuring high precision (\pm 1.5\%±1.5% error tolerance) and rigorous logical consistency.

The coarse temporal resolution of operational data fails to capture short-term ridership variability, leading to inaccurate demand characterization.The assumption of constant vehicle speed and neglect of dwell times (boarding/alighting) introduces systematic errors in schedule calculations.

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