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SYNCHRONIZATION OF THE LAST-TRAIN TIMETABLE CONSIDERING PASSENGER TRANSFER TIME

Summary. Unsynchronized integrated lines in urban rail systems may cause some passengers to miss their last transfer chance. Therefore, passengers move faster in a swarm mentality to catch the last train. This study aims to synchronize the last-train timetable so that the maximum possible number of passengers can be transferred at the transfer stations by waiting for the minimum time. This paper provides a new approach to show that passengers who try to get to the last train at the transfer station move faster and describes the transfer processes with heuristic algorithms. In the case of the Istanbul urban rail system, passengers transfer to the last train 32% faster than average. To find the heuristic algorithm that defines the transfer processes of these passengers, particle swarm algorithms, dragonfly algorithms, and a simulated annealing algorithm were selected for comparison. The transfer times obtained with the particle swarm algorithm and the actual transfer times gave close results between 97.6% and 99.2%. The modified last-train timetable with predicted transfer time increases the number of successful transfers by 28%, decreasing the average waiting time of passengers from 197.27 seconds to 50.56 seconds. In addition, passengers wait 58 seconds less for the transfer to the last train by adjusting the timetable to the modified last train transfer time.

1. INTRODUCTION

Urban rail systems are significant in urban transportation, especially in large cities with heavy traffic [1, 2]. In cities where many people try to get places, urban rail systems are preferred by passengers, as they are integrated, accessible, and fast. Therefore, urban rail system networks have been growing in recent years, and ridership has also been increasing [3]. For example, the number of passengers using urban rail systems in Istanbul daily is more than 2 million [4]. In big cities, passengers may travel by making one or more transfers, either because they have longer travel distances or to travel faster [5].

Some urban rail transport passengers travel by making one or more transfers [5]. Stations where two or more urban railway lines intersect are called transfer stations. Passengers naturally want to get on the train without waiting. However, the priority of the transfer passengers for the last train changes because if the transferred train is the latest, the vital thing for the passengers is to get on the last train [6]. Therefore, synchronized timetables of integrated lines are critical for passenger satisfaction.

The synchronization of the last-train timetable, which constitutes our study subject, has attracted our attention when the spread of urban rail systems and their operating hours are considered. The synchronization of schedules may be more critical for last-train passengers since there are few or no public transportation alternatives, considering that urban rail systems generally are not operated 24 hours. Hence, synchronizing timetables in urban rail systems is vital for urban rail passengers traveling

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by transfer within them, especially at the end of the day, to maximize the number of last-train transfer passengers.

In studies on the synchronization of the timetable for the last train, while the arrival time of the train arriving at the station and the departure time of the transferred train are used as variable parameters, the transfer times of the passengers are generally used as a fixed value [7-10]. Taking an average value of transfer times during hours when passengers are not moving fast may have little effect on the synchronization problems. However, calculating the transfer times and using this value in synchronizing the timetables when the passengers move differently from the average allows us to obtain more successful results because the speed of the passengers at the transfer station varies during the day. For example, passengers who want to get to work or school in the morning may move faster than average to catch the train to which they will transfer. In addition to these times, the transfer process for passengers who want to catch the last train is faster than average. To better define the transfer movements of passengers in this process, we made observations on different days between January 7 and June 14, 2022. These observations are as follows:

- Many passengers thought these were their last chance and moved faster than average.
- Some passengers ran.
- Normally moving passengers tried to accelerate after seeing fast-moving passengers.
- A few passengers moved slower than usual because they did not think they could catch up.

As a result of these determinations, it is clear that the transfer times of the transfer passengers are different from the average transfer times. However, in the transfer process, which is difficult to express mathematically, the passengers act more intuitively, and the observation of swarm psychology has led to the preference of heuristic algorithms for obtaining the last train transfer times.

In studies on the synchronization of the last train schedules, there is a lack of topics related to the transfer processes of the passengers [7-11]. These situations motivated us to study this issue. Therefore, this study has two main aims. The first is that the transfer time is not taken as a constant and average value when synchronizing the last train schedules. The other objective is to find the best heuristic algorithm that can obtain the transfer time for the last train from the average transfer time of passengers. This way, a heuristic algorithm can determine the last train transfer time without measuring at a station where the average transfer time between two lines is known. Therefore, in this paper, the transfer times of the passengers who want to transfer to the last train are predicted with heuristic algorithms and compared to the actual transfer times obtained from observations on the sample line with the expected transfer times. The heuristic algorithm that gives the closest solution to the transfer process is found. As a result, successful passenger transfer numbers and waiting times are seen more realistically by arranging the last-train timetable according to the obtained transfer times.

The rest of this paper is structured as follows. Section 2 presents related studies about the timetable as well as last-train timetable optimization and synchronization problems. Section 3 analyzes this problem's methodology, and the transfer times are presented in Section 4. Then, the case study and its results are presented in more detail in Section 5. Finally, directions for future research and limitations are mentioned in Section 6.

2. LITERATURE REVIEW

Researchers have studied train timetable problems, especially with the development of railway systems in recent years. Many studies have focused on train timetable optimization problems to reduce passenger waiting and traveling times [12-15]. The mixed linear integer programming model [14, 15] and genetic algorithms [12, 13] are generally developed and used in these studies.

Synchronizing problems of the train timetables arise with increased integrated urban rail system lines. The synchronization of the timetable of integrated lines has become an area of study of much interest. The primary purpose of studies on this subject is to reduce passengers' waiting times. Wong et al. [16] also used the mixed linear integer programming model to reduce passenger waiting times at transfer stations, but they had to develop their model with some heuristic values to get a faster solution. In addition, researchers established a model for timetable synchronization using heuristic methods [17-

19]. Guo et al. [17] used particle swarm optimization (PSO) and simulated annealing (SA) algorithms to increase transfer synchronization between two integrated train lines. They tested the model developed on Beijing metro lines and found a 10–20% reduction in travel times. Tian and Niu [18] formulated a heuristic optimization model to improve transfer synchronization in high-speed lines. Abdolmaleki et al. [19] used the local search algorithm to decrease the waiting times of passengers at transfer stations.

Researchers have recently emphasized studies on the last train synchronization in integrated train lines. The research generally focuses on two objectives: to minimize the waiting times of transfer passengers and to provide more successful passenger transfers. Zhou et al. [20] studied the last train coordination model to reduce passenger waiting times and improve passenger accessibility. In another study, Kang et al. [7] established an optimization model considering transferring redundant time and binary variables. They used a genetic SA algorithm to obtain better connections between train lines. Kang et al. [6] developed the last-train model to improve last-train coordination. Kou et al. [8] proposed a departure time optimization method for last trains using a genetic algorithm to increase the number of successful transfer passengers and decrease the waiting times of transfer passengers. Kang and Zhu [9] proposed a heuristic model to minimize redundant transfer times and coordinate a last-train timetable. Li et al. [21] used an adaptive genetic algorithm in their last train coordination model to produce a more synchronized timetable. Yang et al. [22] established an optimization model of the last-train timetable by evaluating successful transfers and train running times. They used the tabu search algorithm and prepared a risk table.

Some studies formulated an optimization model for the last train scheduling problem by using the mixed linear integer programming to provide better service in urban railway networks [20, 23, 24]. There are also recent studies of last-train timetable synchronization that have emphasized accessibility. For example, Chen et al. [25, 26] synchronized the last train schedules with maximum accessibility for the urban rail network in their two studies. Although most of the above studies have been done on one or a few lines, some studies have considered the whole urban rail system network [27]. The last-train timetable synchronization study, made by considering transfers from other transportation modes, is also available in the literature [28]. Some studies developed a solution algorithm for the last train scheduling problem considering train delays [11, 29]. In some studies, the cost function was also considered. For example, Yin et al. [10] developed an optimization model using a genetic algorithm and bi-level programming to obtain better last-train service with minimum operating costs. Other researchers who considered price are Zhang et al. [30]. However, they assessed the total cost of the last trip by considering the alternative routes of the passengers when synchronizing the last train, not the operating cost [30]. Other studies have focused more on potential passenger demand for the later trains. Using GPS or card data, they collected passenger data from other public transport modes, such as taxis and buses. Thus, last-train passenger demand could be estimated from this study [31, 32].

The existing literature on timetable synchronization studies is listed in Table 1, which includes scheduling, objectives, and transfer times. Thus far, studies have focused on the last-train timetable synchronization problem without consideration of transfer processes, as seen in Table 1. The effects of the fast movement of last-train passengers are ignored. Along with the transfer process, no studies have shown that passengers who wish to get on the last train move faster. Therefore, this transfer process, which is different from the normal transfer process, has motivated us to conduct this study.

This study mainly contributes to two issues. Firstly, the effects of the fast movement of passengers who want to catch the last train on the synchronization of the last-train timetable should not be ignored. Therefore, the average and fixed transfer time should not be used in synchronizing the last-train timetables. Secondly, heuristic algorithms can be employed to obtain the transfer times of last-train passengers from standard transfer times. This way, when the average transfer times in standard times are known, the last train transfer times can be calculated by the most appropriate heuristic algorithm.

3. MODEL DEVELOPMENT

The last train coordination model that maximizes successful transfers and minimizes transfer passenger waiting times by adjusting the last train departure time is presented in this section. However, unlike other studies, this study also examines the transfer process of passengers because passengers move faster to catch the last train, especially when there is very little time left for the transfer. This causes the number of passengers reaching the last train to change. Therefore, the primary objectives of this proposed model are to ensure that last-train passengers successfully transfer and to obtain more accurate transfer passenger counts.

Table 1

Literature on the train timetable synchronization problem

Scheduling	Objective	Transfer Time	References
Last trains	Maximizing successful transfers	Known	[24]
	Maximizing successful transfers	Unknown, variable	[23]
	Maximizing successful transfers	Known	[20]
	Maximizing successful transfers	Known	[19]
	Maximizing successful transfers	Known	[15]
	Maximizing successful transfers	Known	[6]
	Minimizing transfer waiting time	Known	[17]
	Minimizing transfer waiting time	Unknown, variable	[21]
	Minimizing transfer waiting time	Known	[18]
	Increasing accessibility	Known	[16]
	Increasing accessibility	Known	[28]
	Increasing accessibility and minimizing transfer waiting time	Known	[27]
	Increasing accessibility and reducing operating cost	Known	[29]
	Determining passenger demand	Unconsidered	[31]
	Determining passenger demand	Known	[32]
Non-last trains	Minimizing waiting time	Unconsidered	[9]
	Minimizing waiting time	Unconsidered	[10]
	Minimizing waiting time	Unconsidered	[7]
	Minimizing waiting time	Unconsidered	[8]
	Minimizing transfer waiting time	Known	[33]
	Minimizing transfer waiting time	Known	[34]

3.1. Problem statement

The synchronization of last-train timetables can be expressed with a small example. For example, imagine a passenger who wants to go home at night using urban rail lines. This passenger wants to go to Station C by transferring from Station A to Station B. They board the train at Station A at 23:45 and get off at Station B at 23:59. Then, some passengers miss the last 00:00 train to Station C because the average transfer time is two minutes. This is a simple example to illustrate this problem. As in the example, some passengers do not get on the train because there is not enough time to transfer. However, the question of how many passengers will miss the train is crucial when it is the last train to run that day. Therefore, a better analysis of the transfer processes is necessary to determine how many passengers will be transferred. Possible transfer scenarios and last train schedules are shown in Table 2 To better explain the sample lines.

Table 2

Transfer status of last trains on sample lines

Possible Transfer scenarios	Transfer direction	Arrival time	Departure time	Transfer time	Transfer status	Wait time [min.]
1.	Line1-Line2	00:03	00:00	2	Impossible	-
2.	Line2-Line1	23:50	00:00	2	Possible	8
3.	Line1-Line2	23:36	23:40	2	Possible	2
4.	Line2-Line1	00:04	00:06	2	Possible	0
5	Line1-Line2	23:59	00:00	2	Possible or not	-

The explanations of five possible transfer scenarios in Table 2 are given below.

In Scenario 1, $t^w < 0$, and $t_d < t_a$, so passengers cannot transfer.

In Scenarios 2–4, $t^w \geq 0$, so passengers can transfer, but it is unclear how many.

In Scenario 5, $t^w < 0$, but $t_d > t_a$, but the passengers cannot transfer. However, there may be a possibility that some passengers can make the transfer in the one minute remaining. This scenario demonstrates the impact of a more realistic calculation of transfer times on both transfer situations and passenger waiting times. This is why we believe that a more realistic analysis of the transfer speeds of the passengers, especially when there is little time for the transfer (in Scenarios 3–5) will be beneficial for synchronizing the last-train timetable.

3.2. Assumptions

The following assumptions are used to give more reasonable results to simplify the model:

- Passengers go to the transfer platform without stopping or waiting during the transfer.
- All passengers are assumed to use escalators since more than 99% of passengers use them.
- The speed of the passengers is not affected by passenger density since passenger density is not high on the last trip.
- Trains are operated according to daily schedules.
- Passengers transfer to the first train, arrive at the platform, and do not want to wait for the next train.

3.3. Notation

The necessary parameters and notation used in the model are listed as follows.

L: the set of last train lines in the urban rail system network $l \in L$, $L = \{l | l = 1, 2, . . . , n\}$, where n is the total number of lines.

S(l): the set of transfer stations on line l, $s \in S(l)$, $S(l) = \{s|s = 1, 2, . . . ,m\}$, where m is the total number of stations.

N: number of transfer passengers

$N_{li\text{-}lj}$: number of transfer passengers from line (i) to line (j)

$t^a_{s, li}$: last train arrival time for line (i) to transfer station

$t^d_{s, lj}$: last train departure time for line (j) from the transfer station

$t^r_{s0\text{-}s, li}$: last train running time for line (i)

$t^{dw}_{s0\text{-}s, li}$: total dwell time of the last train for line (i) until arriving at the transfer station

$t^{dw}_{s, lj}$: dwell time of the last train for line (j) at the transfer station

$t^{tr}_{s, li\text{-}lj}$: transfer time of passengers from line (i) to line (j)

$t_{min}{}^{tr}_{li\text{-}lj}$: minimum transfer time

$t_{max}{}^{tr}_{li\text{-}lj}$: maximum transfer time

$t_{ort}{}^{tr}{}_{li\text{-}lj}$: average transfer time

$t^{w}{}_{s,\ li\text{-}lj}$: the waiting time for the last-train passenger from line (i) to line (j)

$\text{ß}_{\mathrm{li-lj},s}$: ß is used to specify whether passenger transfers from line i to the last train of line j at transfer stations are successful.

3.4. Model objective

The proposed last-train timetable model aims to maximize successful transfers and minimize waiting times.

$$max \sum_{s_i \in S} \sum_{l_i \in L} N_{s_i,\ l_i - l_j} \times \text{ß}_{s_i,\ l_i - l_j} \tag{1}$$

$$min \sum_{s_i \in S} \sum_{l_i \in L} N_{s_i,\ l_i - l_j} \times t^{w}{}_{s_i,\ l_i - l_j} \tag{2}$$

For simplicity, the transfer waiting times shown in Equation 5 must be greater than 0 for passengers to transfer successfully.

$$t^{d}_{s,l1} = t^{d}_{s0,l1} + \sum_{s_i \in S} t^{r}_{s(s-1),l1} + \sum_{s_i \in S} t^{dw}_{s(s-1),l1} + t^{dw}_{s,l1} \tag{3}$$

$$t^{a}_{s,l2} = t^{d}_{s0,l2} + \sum_{s_i \in S} t^{r}_{s(s-1),l2} + \sum_{s_i \in S} t^{dw}_{s(s-1),l2} \tag{4}$$

$$t^{w} = t^{d}_{s,l1} - t^{a}_{s,l2} - t^{tr}_{s,l2-l1} \tag{5}$$

As shown in Equation 6, the parameter $\text{ß}_{\mathrm{l2-l1},s}$ represents this situation.

$$\text{ß}_{\mathrm{li-lj},s} = \begin{cases} 1, & t^{w} \geq 0 \\ 0, & t^{w} < 0 \end{cases} \tag{6}$$

Arrival, departure, transfer, and waiting times are the decision variables of this model, as seen in Equation 5.

4. TRANSFER TIME

This section contains information about estimating the last train transfer time. When there is a fast-moving passenger, many passengers are influenced by each other, and they accelerate to keep up with fast passengers. However, it is complicated to mathematically describe the change in these passengers' speeds. The behavior of transfer passengers is quite similar to swarm psychology. Therefore, in our study, we update the transfer speeds and times of the passengers by using the PSO, SA, and dragonfly algorithms to make comparisons. The designs of the algorithms that estimate the transfer time are described below.

4.1. PSO algorithm design

Kennedy and Eberhart [33] developed the PSO algorithm inspired by the behavior of bird flocks. Birds' searches for food are likened to looking for a solution to a problem. While the birds are looking for food, they follow the bird closest to the food and want to reach their location. Each bird represents a particle in the formula. The fitness values are measured according to the distance of the particles from the food. Particles also form swarms.

Our algorithm minimizes the time between the determined lower and upper limit limits. We determine the lower and upper limits according to the maximum and minimum measuring times. In this transfer time prediction study, the steps of the PSO algorithm are as follows.

Step 1: Each passenger represents a particle, and the passengers in the wagons represent the particle swarm. Therefore, according to Equation 7, each individual must have a speed and position. The transfer speeds of the passengers are determined by the measurements. In addition, the occupancy rates of the wagons and the distances to the escalators are considered.

Step 2: Calculate the initial velocity of the particle with Equation 7:

$$V_{ij} = w * V_{ij} + c_1 * rand1 * \left(P_{ij} - X_{ij}\right) + C_2 * rand2 * \left(G_{ij} - X_{ij}\right), \tag{7}$$

V_{ij}: Initial velocity of the particle
w: Inertia weight value
X_{ij}: Initial position of the particle
P_{ij}: Local best location
G_{ij}: Best position of the swarm
c_1, c_2: Learning coefficients
$rand_1$, $rand_2$: Randomly generated numbers

Step 3: Compare all particles in each generation with the best particle of the previous generation. If it is better, relocate.

Step 4: Compare the best local values and assign the best as the global best.

Step 5: Refresh the velocity and position values of the particles.

4.2. Dragonfly algorithm design

The dragonfly algorithm was used for the first time by Mirjalili [34]. In the dragonfly algorithm, the parameters of food orientation and escaping from the enemy have been added to other swarm movements. Therefore, we think that the ability of dragonflies to update their speed and position without hitting their neighbors while moving toward food sources is suitable for our study. The steps of the dragonfly algorithm are as follows.

Step 1: Swarms consisting of our transfer passengers are created. In our study, each dragonfly represents a passenger who wants to transfer to the last train. The speed data obtained is used to calculate the initial speeds of the passengers.

In the dragonfly algorithm, the objective function for finding food sources is minimized, and the objective function for finding enemies is maximized. This algorithm uses nutrient source values as accurate function values.

Step 2: Update the speeds and locations of transfer passengers with Equations 8 and 9:

$$\nabla X_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\nabla X_t \tag{8}$$

$$X_{t+1} = X_t + \nabla X_{t+1} \quad . \tag{9}$$

∇X: Velocity
X: Position

In Equation 8, s, a, and c represent the separation, alignment, and cohesion coefficients. Equation 9 shows the speeds and positions of the dragonflies. We use s=0.5, a=0.2, c=0.3, f=0.5, e=0.5, and w=0.1 in our algorithm.

Step 3: Add separation functions so that passengers do not collide with each other, alignment functions so that their speeds are close to each other, and cohesion functions so that the positions of the passengers are relative to each other.

Step 4: Update speed and position with the obtained values.

Step 5: Obtain the objective function with these values.

4.3. Simulated annealing algorithm design

The simulated annealing algorithm is used in train timetable synchronization and coordination problems [7, 35, 36]. The simulated annealing algorithm's operation is similar to the iron annealing process, from which its name comes [37]. In other words, a similar approach can be applied to any numerical measurement, just as we heat an iron piece during the iron annealing process and then leave it to cool [38]. Therefore, it is possible to obtain time-dependent values during the heating and cooling of the cells forming the iron. In this way, the best solution is obtained by comparing the solutions found during the cooling of the iron. In our study, the answer, which is formed according to the average transfer times of last-train passengers, will be cooled with the simulated annealing algorithm, and the best solution will be found. In this transfer time prediction study, the steps of the SA algorithm are listed below.

Step 1: Form an initial solution with the average speeds of transfer passengers.

Step 2: Create an initial solution with the average speeds of transfer passengers. Cool the algorithm with the cooling coefficient from the starting to the ending temperature, taking 1000 as the initial temperature and 0.90 as the cooling coefficient.

Step 3: Go to the neighbor; if the place is better, accept it as a solution; if it is worse, calculate the acceptance probability with Equation 10:

$$P = e^{-\Delta/T} \quad . \tag{10}$$

Δ: Neighbour solution - current solution

Step 4: Obtain the best value from iteration within the limit values and set it while the algorithm cools.

5. A CASE STUDY: ISTANBUL RAIL SYSTEM

The length of the urban rail network in Istanbul is 282.95 km. Metro Istanbul serves nearly 3 million passengers daily, with 17 lines of 191.45 km. This study attempts to synchronize the latest trains' timetables of the M1 and M2 metro lines and the Marmaray suburb, considering the daily passenger numbers and integrations from these lines to determine the result of the study and compare it with the actual data. The M1 light rail system, which consists of the M1A and M1B lines, had an average daily passenger number of nearly 420,000 in November 2023. The M1A Yenikapı-Ataturk Airport has 18 stations, and the journey time is 29 minutes. The M1B Yenikapı-Kirazlı line also consists of 13 stations, and the travel time is 25 minutes. The average daily number of passengers in November 2023 on the M2 Yenikapı-Hacısoman line, which consists of 16 stations and is 23.5 km long, was nearly 500,000. Marmaray is a suburban line that connects the Asian and European continents and has a strait crossing. The length of the line, which has 43 stations, is 76 km. Train operation is carried out at intervals of 8 and 15 minutes, and the journey duration is 115 minutes. Marmaray is integrated with the M1 and M2 lines at Yenikapı, with the M4 line at Ayrılıkçeşme, and with the M5 line at Üsküdar.

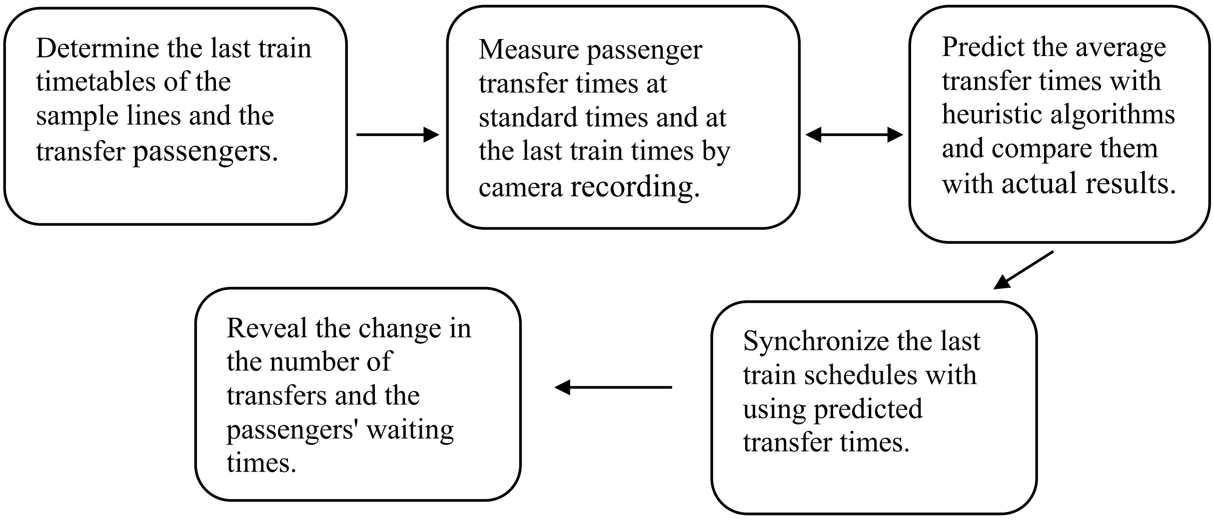

Fig. 1. Flow chart of the solution methodology

This study attempts to synchronize the last-train timetables only at Yenikapı station, considering the daily passengers, transfer passengers, and integrated lines. The summary flow chart of the processes before working on the sample lines is shown in Fig. 1.

According to the flow charts, the original last-train timetables and information about transfer passengers are given in Table 3.

Table 3

Original last-train timetable and transfer passenger information

Transfer station	Transfer direction	Arrival time	Departure time	Number of passengers wishing to transfer	Number of successful transfer passengers	Average waiting time of transferable passengers (s)
Yenikapı	MR-M1A	00:06:00	00:00:00	40	0	-
	MR-M1A	23:51:00	00:00:00	50	50	383
	MR-M1A	23:30:00	23:40:00	50	50	443
	M1A-MR	00:05:00	00:06:00	48	0	-
	M1A-MR	23:26:00	23:30:00	56	56	83
	MR-M1B	00:06:00	23:55:00	40	0	-
	MR-M1B	23:51:00	23:55:00	50	42	63
	MR-M1B	23:30:00	23:35:00	50	50	123
	M1B-MR	23:57:00	00:06:00	48	48	363
	M1B-MR	23:27:00	23:30:00	56	29	3
	MR-M2	00:06:00	00:00:00	30	0	-
	MR-M2	23:51:00	00:00:00	40	40	413
	MR-M2	23:30:00	23:36:00	50	50	233
	M2-MR	23:58:00	00:06:00	72	72	353
	M2-MR	23:26:00	23:30:00	80	80	113
	M2-M1A	23:58:00	00:00:00	48	36	17
	M1A-M2	23:56:00	00:00:00	40	40	137
	M2-M1B	23:50:00	23:55:00	48	48	176
	M1B-M2	23:57:00	00:00:00	40	40	56
Average :						197.27

The passengers' transfer times consist of time spent walking on the platform, climbing and descending the escalator, and walking in the turnstile area. Therefore, the position of the wagon the passengers travel on affects the walking time on the platform. The M1 light metro line is operated by trains with four wagons, the M2 metro line is operated by trains with eight wagons, and the suburb of Marmaray is operated by trains with 10 wagon trains. Therefore, we consider the passengers on the M1 and M2 lines as eight swarms and the passengers on the Marmaray line as 10 swarms when determining the transfer time.

We obtained the passengers' average and fastest transfer times (shown in Table 4) based on approximately 50 measurements made between January 19 and June 20, 2022. The average transfer time measurements were taken during daytime hours when the passenger density was not high, and the last train transfer time measurements were made after 23:00. The difference between the average transfer time in standard times and the transfer times in the last-train time is shown in Table 4.

5.1. Prediction of transfer times

Predicting transfer times involves finding the algorithm that gives the closest result to the change between the average times. The algorithms were coded and decoded in the MATLAB program on the researcher’s laptop. First, swarms were formed based on the number of wagons. The average transfer times in Table 4 were updated with the PSO, SA, and dragonfly algorithms.

Table 4

Transfer times of passengers

Transfer station	Transfer direction	Average transfer time (s)	Average transfer time for last train (s)	Rate of change in average transfer times
Yenikapı	MR-M1B	176.5	119	33%
	MR-M1A	157.6	102	35%
	MR-M2	127.4	91	29%
	M2-M1A	103.5	69.2	33%
	M2-M1B	123.6	89.2	28%

There was a decrease in the average transfer times between 28% and 35%, as seen in Table 4.

The transfer time values predicted by the algorithms obtained after 50 iterations are shown in Table 5. The table also shows that the transfer times indicated with PSO give results very close to the transfer times of the last train transfer passengers.

Table 5

Transfer times of passengers predicted with algorithms

Transfer station	Transfer direction	Average transfer time (s)	Average transfer time for last train (s)	Predicted average transfer time for last train (s)		
				PSO	SA	Dragonfly
Yenikapı	MR-M1B	176.5	119	120	142.4	143.7
	MR-M1A	157.6	102	104.1	121.5	128.8
	MR-M2	127.4	91	93.2	103.6	102.7
	M2-M1A	103.5	69.2	68.1	81.4	76.4
	M2-M1B	123.6	89.2	90	93.4	101.3

5.2. Synchronization of the last-train timetable

The integrated last-train timetable was synchronized using the transfer time obtained with the PSO algorithm to increase the number of successful transfers by passengers. Although there are usually more differences between the transfer times of the passengers, the differences between the transfer times are smaller because the passengers who want to catch the last train move faster than normal. Table 6 illustrates this situation. The difference between the average and maximum transfer times in standard times is between 46 and 83 seconds; for the last train, this time is 40–55 seconds.

Table 6

Comparison of transfer times of passengers

Transfer station	Transfer direction	Average real transfer time of transfer passengers (s)	Maximum real transfer time of transfer passengers (s)	Predicted average transfer time of last train transfer passengers(s)	Predicted maximum transfer time of last train transfer passengers(s)
Yenikapı	MR-M1B	176.5	259	120	175
	MR-M1A	157.6	238	104.1	158
	MR-M2	127.4	173.5	93.2	136
	M2-M1A	103.5	151.1	68.1	110
	M2-M1B	123.6	171.1	90	130

Table 6 shows a maximum of 55 seconds between the average times and the time of the slowest passenger in the last train transfer time data obtained by the PSO algorithm. Thus, the last-train timetables are synchronized so that all passengers can catch the last train and so that all waiting times for transfer passengers can be minimized.

Table 7

Comparison of transfer times of passengers

Transfer station	Transfer direction	Arrival time	Departure time	Number of passengers wishing to transfer	Number of successful transfer passengers	Average waiting time of transferable passengers (s)
Yenikapı	MR-M1A	00:06:00	00:08:38	40	40	54
	MR-M1A	23:51:00	23:53:38	50	50	54
	MR-M1A	23:30:00	23:32:38	50	50	54
	M1A-MR	00:05:00	00:07:38	48	48	54
	M1A-MR	23:26:00	23:28:38	56	56	54
	MR-M1B	00:06:00	00:08:55	40	40	55
	MR-M1B	23:51:00	23:53:55	50	50	55
	MR-M1B	23:30:00	23:32:55	50	50	55
	M1B-MR	23:57:00	23:59:55	48	48	55
	M1B-MR	23:27:00	23:29:55	56	56	55
	MR-M2	00:06:00	00:08:16	30	30	43
	MR-M2	23:51:00	23:53:16	40	40	43
	MR-M2	23:30:00	23:32:16	50	50	43
	M2-MR	23:58:00	00:00:16	72	72	43
	M2-MR	23:26:00	23:28:16	80	80	43
	M2-M1A	23:58:00	23:59:50	48	48	42
	M1A-M2	23:56:00	23:57:50	40	40	42
	M2-M1B	23:50:00	23:52:10	48	48	60
	M1B-M2	23:57:00	23:59:10	40	40	60
					Average :	50.56

The maximum last train transfer times in Table 6 were used as the transfer time values in Equation 1. In this way, the timetable in Table 7, which allows all passengers to be transferred, was obtained.

There are differences in the departure times of the last trains ranging from five seconds to 13 minutes, 55 seconds based on a comparison of Tables 3 and 7.

Table 8

Comparison of transfer times of passengers

Transfer station		Successful transfer passengers	Average waiting time of transferable passengers (s)
Yenikapı	Original	731	197.27
	Standart	936	108.83
	Optimized	936	50.56
	Improvement	28%	74%

Table 8 shows that successful transfers increased by 28% and that the average waiting time of transferred passengers decreased by 74%. If timetables are adjusted according to the maximum transfer time in standard hours, the average waiting time for passengers is 108.83 seconds.

6. CONCLUSIONS

This paper describes the last train synchronization problem and proposes a prediction algorithm for the last train transfer time to describe the actual transfer process. The data on the transfer times of the passengers were collected at the Metro Istanbul Yenikapı transfer station between January 19 and June 20, 2022, at standard times and at the last train times to explain this transfer process. According to these data, passengers transfer to the last train 32% faster than average. Particle swarm, dragonfly, and simulated annealing algorithms from heuristic algorithms were used to predict the standard transfer times of these passengers. The particle swarm algorithm gave the closest result to this change, with a 1-2% difference. This paper focused on synchronizing last-train timetables with real transfer times so that the maximum number of passengers can be transferred at the transfer stations while waiting for the shortest time possible. The synchronized timetable increases the successful transfers by 28% and decreases passengers' waiting times from 197.27 seconds to 50.56 seconds, as seen in Table 8. The passengers wait 58 seconds less for the transfer to the last train when the timetable is adjusted based on the optimized last train transfer time. In other words, if this study were optimized according to the standard transfer time like other studies, a total of 909 additional minutes of waiting time would have occurred for the 936 transfer passengers in the sample.

In summary, the objectives of this study were to emphasize that the last train transfer times are different from usual transfer times and to find the best heuristic algorithm that calculates the last train transfer time based on the standard transfer time. This study contributes to the literature by optimizing standard transfer times and using them to synchronize last-train schedules.

The transfer time is essential in synchronizing timetables, and we believe it will create awareness that it should not be taken as a common value in future studies. Since train timetables may change in real operations, future studies on the synchronization of last-train timetables can use dynamic schedules.

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