Online Appendix for

"A coordinated optimization research on timetable and skip-stop pattern for urban rail lines"

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Appendix A: Comparisons of modeling scenarios in the urban rail optimization

Table A.1 provides a comparison with several major related studies.

Table A.1. Comparisons of modeling scenarios in the urban rail optimization.

Objective	Input demand	Strategy	Fairness	Transfer	Key references
min TWT	TDODD	Timetabling	No	No	Niu et al.(2013)
min OC & TWT	TDSD	Skip-stopping +timetabling	No	No	Wang et al.(2014)
min TTT	TDODD	Skip-stopping	No	No	Jamili et al.(2015)
min TWT	TDODD	Timetabling	No	No	Niu et al. (2015)
min max TWT	TDODD	Timetabling	Yes	No	Wu et al.(2015)
min OC	TDSD	Skip-stopping +timetabling	No	No	Shi et al.(2017)
min OC	TDSD	Skip-stopping	No	No	Yang et al.(2019)
min OC	TDODD	Timetabling	Yes	No	Li et al.(2019)
min longest WT	GROUP	Skip-stopping +timetabling	Yes	No	Yang et al.(2021)
min OC & TWT	TDODD	Skip-stopping +timetabling	No	No	Yang et al.(2021)
min longest WT	ITDODP	Skip-stopping +timetabling	Yes	Yes	This paper

Note: WT: waiting time, TWT: total waiting time, TTT: total travel time, OC: Operational cost, TDODD: time-dependent O-D demand, ITDODP: individual time-dependent O-D passenger, TDSD: time-dependent section demand, Group: group of same O-D passengers.

Appendix B: Notations and definition

Fig.B.1. illustrates the physical structure of the rail transit line, which has two directions, namely “up” and “down”, and a total of N platforms. Each passenger has an independent arrival time and O-D demand. Passengers follow a strict FIFO rule.

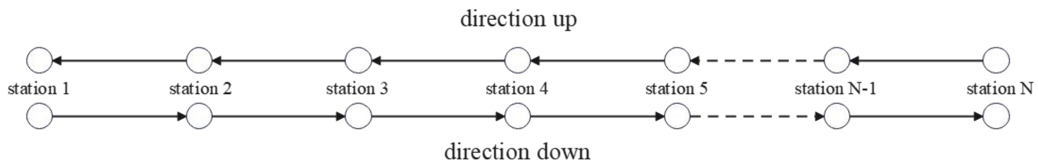

Fig.B.1. The physical structure of our rail transit line

Table B.1. Notations and definition

Notation	Definition
Sets	
$direction$	Rail’s direction. $direction \in \{"up", "down"\}$
I^{up}	Set of rails which $direction$ is "up"
I^{down}	Set of rails which $direction$ is "$down$"
$I^{direction}$	Set of rails, $i^{up} \in \{1^{up}, 2^{up}, \dots, \lvert I^{up}\rvert^{up}\}$, $i^{down} \in \left\{1^{down}, 3^{down}, \dots, \left\lvert I^{down}\right\rvert^{down}\right\}$
J	Set of stations
j, k	Number of stations, $j, k \in \{1,2,3, \dots, \lvert J\rvert\}$
P	Set of passengers
p, l	Number of passengers, $p, l \in \{1,2,3, \dots, \lvert P\rvert\}$
Parameters	
T	Length of the operating period
$t_{direction}^{first}$	The first rail’s departure time in $direction$
t_{min}^{seq}	The minimum interval of sequent rails
C	Train capacity
o_p	Origin station of passenger p
d_p	Destination station of passenger p
t_p	Arrival time of passenger at origin station
$s_{i^d j}$	Dwelling time of Rail i^d in station j
$\tau_{j,j+1}, \tau_{j,j-1}$	Running time between two adjacent stations
t_h	Minimum headway between two adjacent stations
S	Maximum skipping times of one rail
SS	Maximum sequent skipping times of one rail
$Skip$	Maximum times of one station to be skipped
$Skip - Skip$	Maximum times of two stations when at least one being skipped
Variables	
X	Indicator of the stop-skipping strategy of rails, $\lvert I\rvert \times \lvert J\rvert$ matrix
$x_{i^d j}$	Indicator of the stop-skipping decision of rail i^d: $x_{i^d j} = 0$ if station j is skipped, and $x_{i^d j} = 1$, otherwise
T_d	The timetable of rails, $\lvert I\rvert - length$ vector

t_{i^d}	The departure time of rail i^d
Y_p	passenger p's travelling strategy when they can transfer, including $y_{pi^d}, s_{pi^d}, t_{pi^d}$
y_{pi^d}	Indicator of the travelling decision of passenger p: y_{pi^d}= 0 if passenger p choose rail i^d, and y_{pi^d} = 1, otherwise
s_{pi^d}	Station where passenger p gets on the rail in the strategy
t_{pi^d}	Passenger p's arriving time of each station where i^d stops in the strategy
a_{i^dj}	Arrival time of rail i^d at station j
d_{i^dj}	Departure time of rail i^d from station j
c_{i^dj}	The number of passengers remained when rails depart from stations
W_p	Passenger's waiting time

Table B.2. Groups of passengers

Group	definition
$\widehat{P}_{j^{up}}$	Group of passengers departing from station j with direction "up"
$\widehat{P}_{j^{down}}$	Group of passengers departing from station j with direction "down"
$\breve{P}_{j^{up}}$	Group of passengers going to station j with direction "up"
$\breve{P}_{j^{down}}$	Group of passengers going to station j with direction "down"

Appendix C: Our algorithms

Algorithm 1: passenger choose

Input: passenger information; timetable and skip-stop strategy

Output: passenger travel choice

for $p \in P, i \in I$ **do**
  calculate the latest direct subway i^*'s arrival time to o_p: $a_{i^*o_p}$
  set $i_j \in I_j$ where $t_p < a_{i_jo_p} < a_{i^*o_p}$ and i_j stops at station o_p meanwhile skips d_p
  set $i_k \in I_k$ where $t_p < a_{i_ko_p} < a_{i^*o_p}$ and i_k skips station o_p meanwhile stops at d_p
  #forward transfer
  for $i_j \in I_j, i_k \in I_k$ **do**
    if $a_{i_jo_p} < a_{i_ko_p}$ and there exists at least one station $l \in (j,k)$ where i_j, i_k stop **then**
      passenger p can choose forward transfer, keep it as s_1
    end if
  end for
  #O-turn transfer
  for $i_j \in I_j$ **do**
    if there exists at least one rail i_k meeting $a_{i_ko_p} \in (a_{i_jo_p}, a_{i^*o_p})$ **then**
      if there exists at least one station l where i_j, i_k stop **then**
        passenger p can choose O-turn transfer, keep it as s_2
      end if
    end if
  end for
  #D-turn transfer
  for $i_k \in I_k$ **do**
    if there exists at least one rail l which stops at o_p **then**
      if passenger p can get i_k by l **then**

passenger p can choose D-turn transfer, keep it as s_3
end if
end if
end for
Compare travel time of s_1, s_2, s_3 together with $a_{i^* o_p}$
choose the minimum as p's strategy
end for

Algorithm 2: genetic algorithm

Input: population size: n; maximum number of iteration: max_$iter$
Output: global best timetable and skip-stop strategy
generate initial population of n strategy chromosomes
set iteration counter $c = 0$
compute the fitness value of each chromosome
while $c < max\_iter$ **do**
calculate each chromosome's fitness according to **Algorithm 3**
select a pair of chromosomes from initial population by fitness
apply crossover on selected pair to generate offspring
apply mutation on each chromosome
increment c by 1
end while
return the best timetable and skip-stop strategy

Algorithm 3: fitness

Input: passenger information; one chromosome
Output: chromosome's fitness
decode chromosome to get the timetable and skip-stop strategy
for $p \in P$ **do**
passenger p chooses travel strategy according to **Algorithm 1**
end for
set iteration $t = 0$
while $t < T$ **do**
subway enters the station
passenger get off the rail according to the travel strategy
passenger get on the rail according to the travel strategy
accumulate the waiting time of each passenger and add it to W_p
rail leaves the station
increment t by 1
end while
return $max\, W_p$

1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	-1	0	1	-1	0	0

Fig .C.1. An example of strategy encoding

The strategy indicates that the second trip in the upstream direction skips the second station, and the third trip in the downstream direction skips the third station. The first trip in both the upstream and downstream directions depart 1 minute earlier. The third trip in the upstream direction departs 1 minute later. The decoding process simply follow the encoding steps.

Appendix D: More information about the results

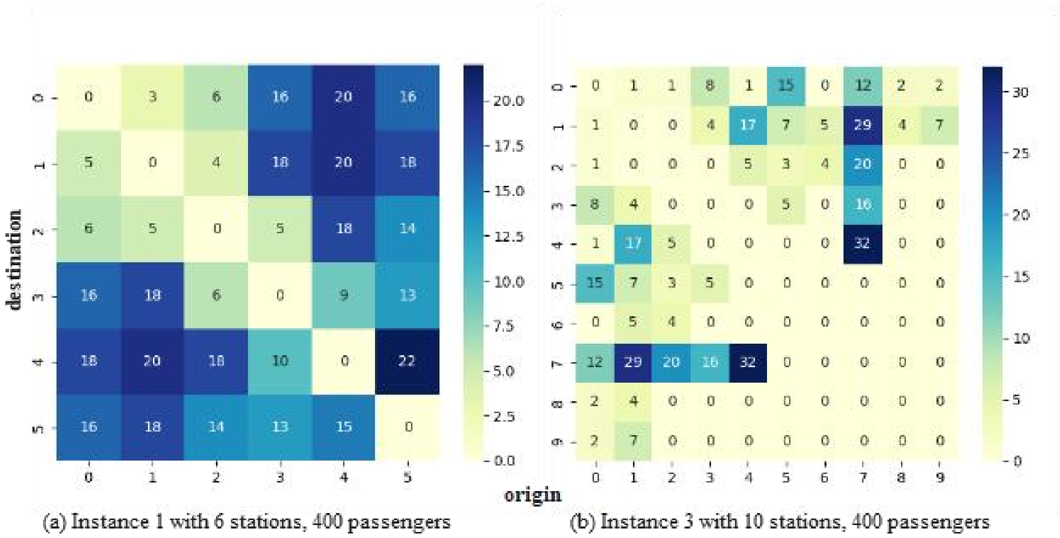

Fig. D.1. Passengers' O-d demand matrix

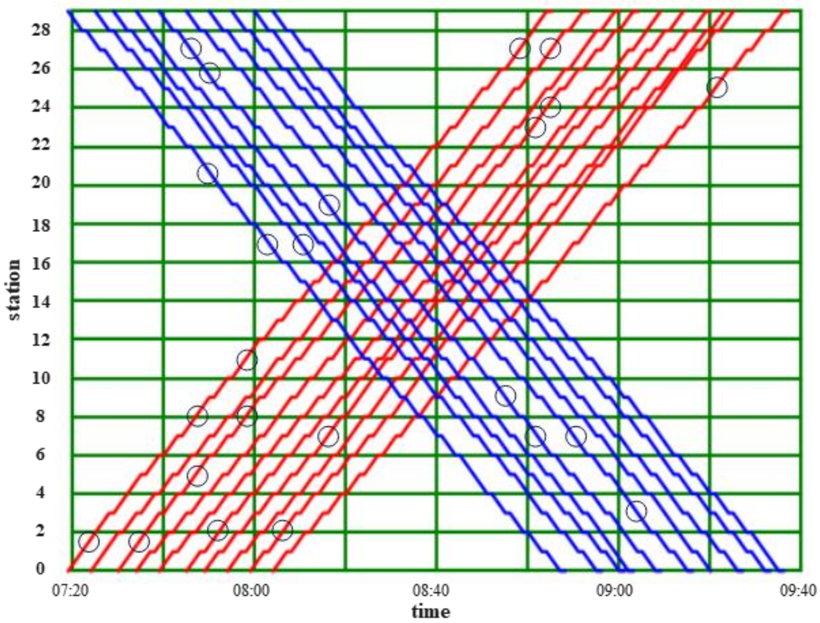

Fig. D.2. The timetable with optimized skip-stopping pattern in the Line 1

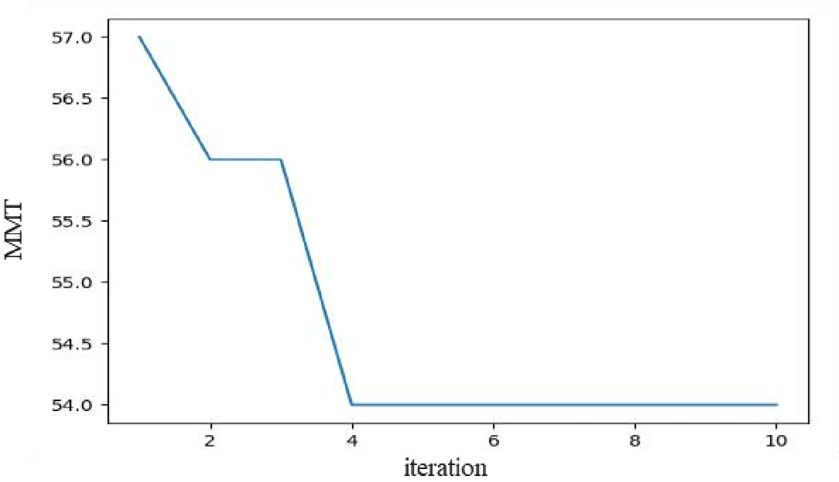

Fig. D.3. The convergence process of our GA algorithm