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Invited Paper

High-speed, high-density train allocation

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ABSTRACT

In order to realise higher capacity and shorter passengers' time with restricted track capacity, new systematic methods of making and evaluating many good new train stopping patterns have been discussed.

This paper includes three major proposals; (1) a new trains' loci chart has been established, whose time axis is taken as normalised time difference between stopping and passing trains, the expression of which is more easily understandable for us and more easily treatable for a computer than ordinary expression, (2) performance of zonal separation train scheduling, which is known most suitable for typical commuter lines connecting city centre and suburban area, has been improved by selective additional stops, and (3) a method of finding the best stopping pattern out of all possible patterns which are made systematically by a computer with a section of a line, number of trains, cycle time and number of trains serving each station given.

Combination of the above proposals can realise theoretically best train scheduling as far as the data given and assumptions taken are reasonable.

INTRODUCTION

Urban and intercity rail services are very important from social viewpoints such as traffic safety and environmental friendliness, etc. They are, however, not so attractive from users' viewpoints because of poor train scheduling. Especially, in densely populated area with insufficient social investment, trains are congested and passengers' time is too long. If number of tracks could be increased and each kind of trains such as fast, semi-fast and local, could run with its own track, the problems would be solved, but it is very difficult to construct additional tracks in densely populated area. Under these circumstances proposals given in this paper would help railways receive much better social acceptance through improved passengers' services.

The basic adea of the improvement is reduction of number of stops per each train; typically, 1 minute time is consumed at each intermediate stop with time loss of 15 seconds for deceleration, 25 seconds for station stop and 20 seconds for acceleration, and minimum practical train headway is 2 minutes for two consecutive stopping trains but less than one minute for two consecutive passing trains.

The problem is the fact that reduction of number of stops does not automatically improve the situation; it may be easily understandable that if number of stops is unreasonably adopted, some passengers have to wait long until a later train serving their destination, or have to change trains which had not be necessary, or even they can never be reached at their destination, and passing trains can not always run faster because of the movement of preceding trains.

This paper deals with how to determine intermediate stops of a group of trains in order to minimise passengers' time and maximise train capacity, and proposes the methods of finding the best solution out of all possible solutions both made by a computer.

1. USEFUL CHART OF EVALUATING REASONABLE TRAIN STOPPING PATTERNS AND ITS EXPRESSION FOR A COMPUTER USING BINARY NUMBER

In order to realise fast and frequent train scheduling, it is very important to express time difference required for relevant trains as purely as possible. From this respect, train loci in distance - time surface shown in such a way that time of each train is shown by actual time minus standard time of the fastest train was proposed by the author in theprevious paper[1]. In this paper, time difference is made at station only by whether the train stops or passes, and because actual distance or time required between adjacent stations has little meaning, distance axis is taken as order of the stations only. Practical train headways between two consecutive trains are fortunately close to the time difference above for passing trains and two times that for stopping trains. So, if time is expressed as normalised by the difference between stopping and passing trains, which is typically 1 minute, we can draw the train loci on the general section paper rather than specially prepared time - distance chart. The fact that train loci exist only on the line of the general section paper or a shortest 45 degree line connecting diagonal points means that the loci are easily expreesed by 1's and 0's on the computer as shown in **Table 1**.

Table 1 Expression of Figure 2a for computer

	1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1
stopping	1 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0
pattern	1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0
	1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0
	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
operating	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
pattern	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Figure 1 shows typical train loci without additional loss times. If a passing train follows a stopping train with a relatively short headway, it can not run at normal

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speed, i.e. an additional time loss takes place. In this case the train loci can be expressed as in **Figure 2a** as far as possibility of dense train allocation is concerned.

In practical application, reduction of running speed may better be put at other places such as in **Figure 2b** or **2c**, by some reason such as energy saving, reducing running noise problem, increasing chance of opening level crossing barrier, etc. But this modification can be made at a later step of making train scheduling than discussion in this paper.

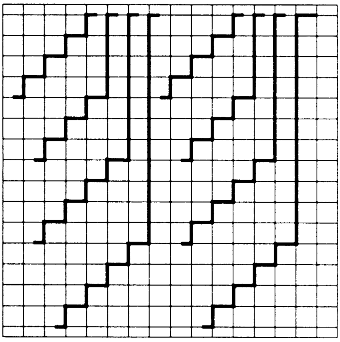
Figure1 Expression of loss time only

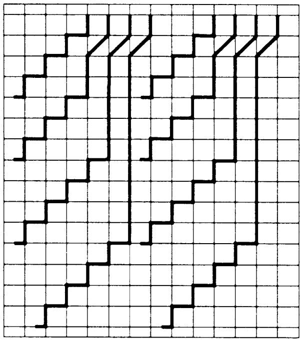
Figure2a Expression for slow running

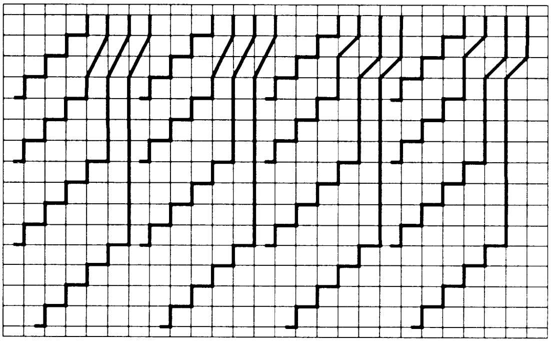
Figure2b Figure2c
Expression for slow running

2. IMPROVEMENT OF ZONAL SEPARATION TYPE TRAIN SCHEDULING

On a commuter line whose track rediates from city centre to suburban residential area, it is known reasonable from the viewpoint of fast and frequent service to carry passengers of a zone only by stopping at each station of the given zone and by going directly to the city centre terminus without intermediate stops.(**Figure 3**)
In this configuration, considerably high frequency train operation can be made without sacrificing train speed of any kind. But if more capacity is required, train frequency must be increased as shown in **Figure 2s**, which reduces speeds of passing trains. If *all* passengers travel between the city terminal station and passengers' nearest stations only, this type of train scheduling is the best solution without doubt, but there are also minor passengers who travel from one zone to another far

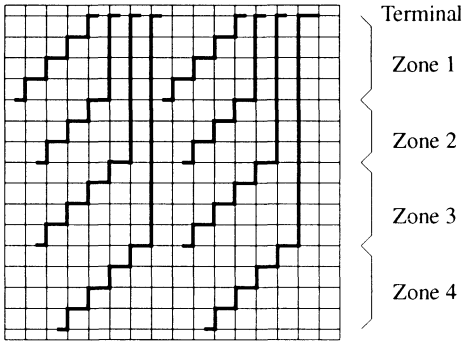

Figure 3 Zonal separation

apart from each other, and they have to transfer many times. As an index, traffic volume ratio of that between a terminal and any other station to that between non-terminal stations has been examined for several commuter lines. If this ratio is very high, for example 50 or over, the prototype zonal separation type train scheduling works fairly well, but if the ratio is not so high, such as 20 or so, not a few passengers have to change trains at the boundary stations and this requires long travelling time and produces peak traffic demand at other places than just out of city terminal which has the biggest cross-sectional demand as shown in **Figure 4**.

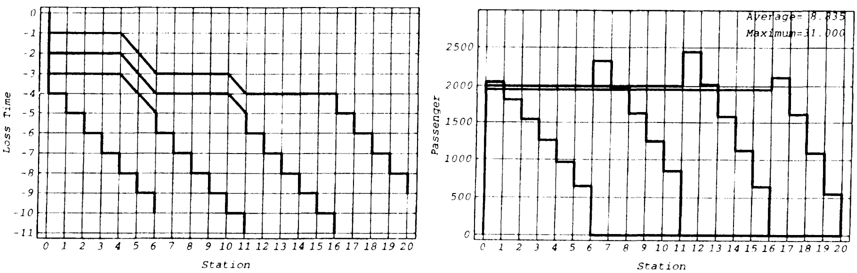

Figure 4 Basic pattern

In this chapter, modification of the prototype zonal separation train scheduling pattern will be discussed so that too many times of transfers and peak traffic demand due to interzonal transferring passengers can be eliminated. The basic idea of this improvement is introducing additional stops at suitable stations which reduces total number of transfers and total travelling time of all the passengers but does not change substantially the load balances among trains serving different zones. If additional stops are made on a section where passing trains have to run slowly to keep train frequency higher than the originally designed value, loss of travelling time due to additional stops may be negligible. Fortunately, reduction of passing train speed tends to take place at inner zones because of shorter station spacing and therefore less patronage per station.

Two effective means have been found through many case studies and computer simulations: Split of a zone into two and served by alternate trains, and additional stops of passing trains.

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Suppose the original pattern as in **Figure 4**. In this case loss times of 2 or 3 minutes for passing trains are inevitable in order to accomodate 4 trains every 8 minutes, or 30 trains per hour. If the first zone is divided into two subzones, shown in **Figure 5**, slow running may be minimised and therfore average loss time is reduced, but maximum loss time and peak congestion is even worsened. **Figure 6** shows an effect of additional stops with slightly modified zonal boundary. Thanks to an additional stop for the zone 3 train and two additional stops for the zone 4 train, maximum loss time has been greatly reduced. If the two countermeasures are taken together, better transportation will be expected; out of 100 patterns automatically produced by computer, the selected best is shown in **Figure 7**, which has very low value of average loss time and gives no peak demand due to transfer of trains. Similar output can be given as in **Figure 8** if a reduced cycle time of a group of trains from 8 minutes to 7, or strictly speaking, from 16 minutes to 14, this time the best solution was found out of 6720 cases. The performances given in the previous figures are shown in **Table 2**.

Table 2. Performances of several patterns

figure	pattern	loss time in min. average	maximum	passengers/ train (max)
Figure 4	original pattern	8.835	31	2450
Figure 5	split of zone 1	8.504	41	2920
Figure 6	additional stops	8.559	18	2100
Figure 7	both split & add. stops	8.121	27	2260
Figure 8	higher density as above	8.274	24	1900

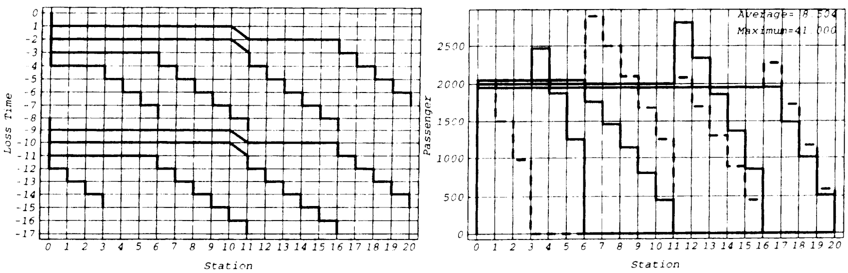

Figure 5 Split of zone 1

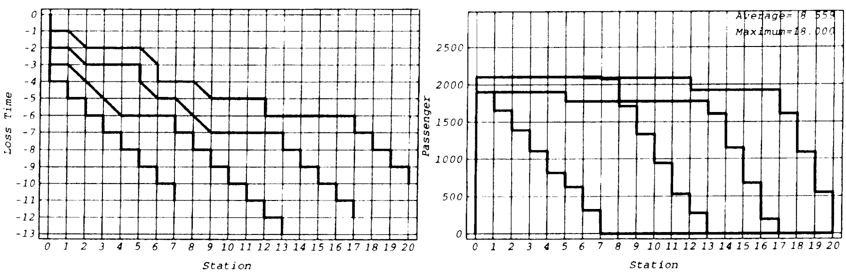

Figure 6 Additional stops

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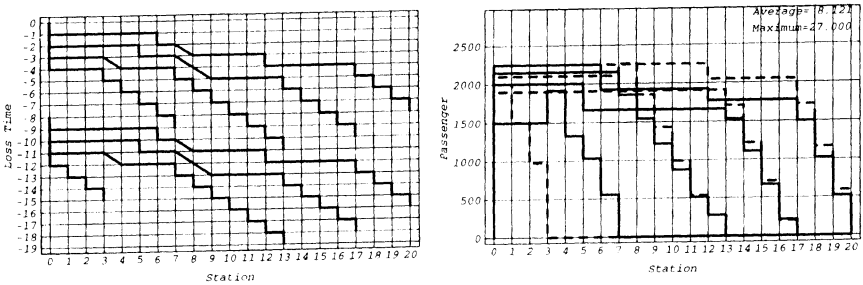

Figure 7 Split & add. stops

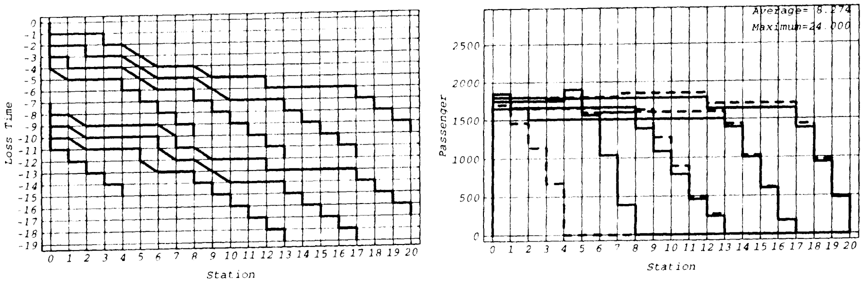

Figure 8 Higher density of Figure 7

3. SKIP-STOP SCHEME WITHOUT LOSS OF FREQUENCY AND RUNNING TIME

In most commuter lines, there are big and small stations in terms of number of passengers using. If trains are operated frequently, it can not be justified that all trains or all trains of a category stop at the smallest station. Contrary to this, it seems reasonable that, according to number of passengers using, each station has its own number of trains served out of a given number of trains grouped. There are also several stations big enough to be served by all trains.

In this circumstance, travelling time of a group of trains can be reduced by reducing total number of station-stops. In this chapter, reasonable determination of number of trains grouped, number of stops, and obtaining best allocation of a group of trains are discussed.

At first, consider a section of a line bounded by big enough stations where all trains stop. Assume minimum train headway and no slack time on any train, number of stops at intermediate stations of each train being the same, which means the total number of stops is number of trains grouped times number of intermediate stations. So, the first thing to determine is number of trains grouped and number of stops by a group of trains at each station. If too small numbers are chosen, such as 10 stops by 5 trains for 7 intermediate stations, there will be many paths which could not be connected, i.e. no service between these stations for ever unless going to a boundary station and back. But if too big numbers are chosen in order to avoid station pairs unconnected, such as 60 stops by 20 trains for 7 intermediate stations, cycle time becomes too long resulting too long waiting time for some passengers. Easier solution by increasing number of stops per train, such as 30 stops by 5 trains for 7 intermediate stations, brings little improvement compared with stopping trains only, or 7 stops by 1 train.

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Relationship among number of intermediate stations, number of stops per train, minimum necessary number of trains per cycle and minimum number of stops per cycle at station in order to connect any station pair is shown in **Table 3**.

Table 3 Necessary numbers of trains & stops etc. to connect each OD pair

Number of intermediate stations	2	3	3	4	4	4	5	5	5	5	6	6	6	6
Number of stops per train	2	2	3	2	3	4	2	3	4	5	2	3	4	5
Min. number of trains / cycle	1	3	1	6	3	1	10	4	3	1	15	6	3	3
Min. number of stops / cycle	1	2	1	3	2	1	4	2	2	1	5	3	2	2
Number of intermediate stations	6	7	7	7	7	7	7	8	8	8	8	8	8	8
Number of stops per train	6	2	3	4	5	6	7	2	3	4	5	6	7	8
Min. number of trains / cycle	1	21	7	4	3	3	1	28	11	6	4	3	3	1
Min. number of stops / cycle	1	6	3	2	2	2	1	7	4	3	2	2	2	1

It is not always necessary that any origin-destination (OD) pair is connected. Sometimes it may be more important to go faster to the next big station than to connect very scaracely used pairs. So, after consulting the table above, one can determine a candidate of operation mode i.e. no. of interm. stations, no. of stops, no. of trains/cycle and no. of stops/cycle as 7,3,7,3. A computer program to generate all possible combination of stopping patterns for the given mode has been developed and out of them the best, and worst if necessary, solution can now be obtained according to evaluation.

Four examples obtained by this program are shown in **Figure 9-12**. **Figures 9** and **10** are the best and worst solutions respectively from number of unconnected pairs. The best pattern shown in **Figure 9** provides all 21 pairs connected by the minimum number of trains and stops, but only 9 pairs connected by **Figure 10**. **Figures 11** and **12** are those from deviation of stopping interval at stations.

After obtaining the best solution or solutions of connecting each adjacent big stations as the segments of total train scheduling, we can combine the segments rather easily. If there is a big volume of demand between small stations beyond big station(s), combination of segments should be made so that this traffic is directly reached. Although the difference is normally small, combination can be chosen out of candidates so as to minimise number of necessary transfers by passengers.

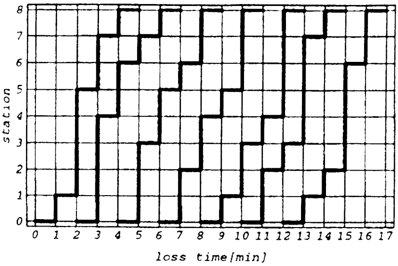

Figure 9 Best of OD coupled

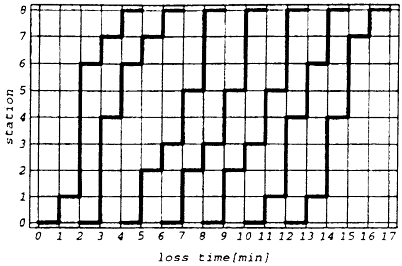

Figure 10 Worst of OD coupled

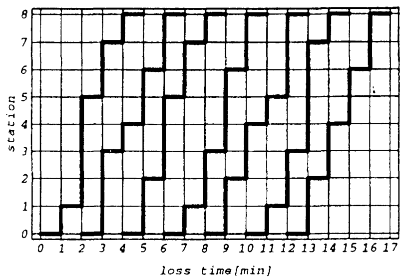

Figure 11 Best of stop interval

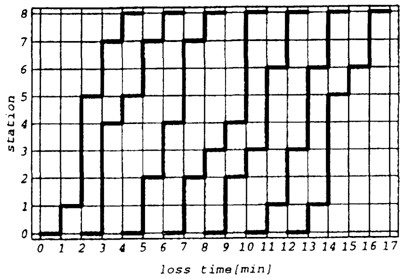

Figure 12 Worst of stop interval

CONCLUSION

Improvement of train scheduling by way of decreasing total number of stops has nearly been theoretically developed, but from passengers' orientation, it seems impossible to adopt this scheme in full until individual guidance system, such as Smart Card Ticket, is introduced.

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