Determination of sub optimal frequencies of suburban trains using simulation

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In this research work a simulation model is developed to study the effects of change in frequency or capacity of suburban trains on waiting time for the given demands at various suburban railway stations. With the help of the simulation model optimal frequencies (or headways) of suburban trains is determined. As the study area Madras Beach to Tambaram meter gauge suburban railway section in Chennai, India was taken and extensive data collection regarding sale of card and season tickets was done for 16 hrs from 6.00 a.m. to 10.00 p.m.. Traffic surveys at suburban railway platforms were conducted to study arrival pattern of commuters. Simulation model had been developed to see the effect of change in frequency and/or capacity of trains on waiting time of passengers at different railway stations. The developed model has been used to study the effect of operating 8 and 9. coach trains with different headways. It is determined that 8 coach train with 5 minute headway and 9 coach train with 7 minute headway gave better results among other alternatives.

Introduction

Substantial expansion of original city boundaries and high levels of industrial and commercial activities have accompanied the exploding population growth particularly in metropolitan cities of developing countries like India. These changes have placed new and heavy demands on their transport systems. Mainly because of resource constraints these cities are unable to meet these demands. Pressure on transport systems in the cities keeps increasing year after year. The spectre of runaway traffic growth patterns, ballooning private vehicles, sluggishness in growth of road network, gross inadequacy of public transport, long journeys and the consumption of more fuel, all together create chaotic traffic conditions day after day. Increase in household incomes creates a greater prosperity for travel and consequently the riding habit keeps on growing. Under such worsened conditions it is essential to reduce the use of private and intermediate transportation. If the efficiency of public transportation is increased people would like to shift to public transportation and thereby there will be lesser degree use of private and intermediate transportation. Suburban railway and public buses are two major public transport services, which play vital role in the metropolitan cities of developing countries like Mumbai, Chennai and Kolkatta in India.

It is found that in most of the developing countries the scheduling of public transport services is done without appropriate study, which leads to commuter dissatisfaction. The first and foremost important task is to optimize the services of suburban trains so as to reduce the waiting time at suburban railway stations and there after appropriate co-ordination with public bus services must be established. With the stochastic nature of travel demand and train arrivals at stations simulation techniques can be gainfully deployed. The objective of the study is to develop a simulation model to see the effect of change in frequencies and capacity of trains on waiting time of passengers for the given demands at various suburban railway stations. Thus in this study an attempt is made to obtain best possible frequencies of suburban trains to attain desired loading level for the existing capacity and enhanced capacity of trains. The validation of simulation model is done by comparing existing and simulated values of average waiting time of passengers, boarding, alighting and on board passengers in trains.

Data Collection

Chennai (Madras), which is one of the major metropolitan cities in India, was taken as case study. Madras Beach to Tambaram which is a meter gauge suburban railway line passes through heart of the city was taken as case study corridor. The data collection was done during July/August 1992 from all the suburban railway station in between the above two stations. Various stations starting from Madras Beach are: Madras Beach (MB), Madras Fort (MF), Madras Park (MP), Madras Egmore (MS), Chetpet (MSC or MC), Nungambakkam (NBK or NB), Kodambakkam (MKK or MK), Mambalam (MBM or MB), Saidapet (SP), Guindy (GDYor GD), St. Thomas Mount (STM or ST), Pallavantangle (PZA or PZ), Minambakkam (MN), Tirisulam(TLM or TL), Palavaram (PV), Chrompet (CMP or CM), Tambaram Sanitorium (TBMS or TS) and Tambaram (TBM or TB). Following details were collected for simulation model

- Number of stations, distance between stations, inter-station travel time, schedule of trains and capacity of trains.
- Boarding and alighting pattern of passengers at different stations.
- Details of season (monthly pass) and card ticket holders using suburban trains.
- Hourly sale of card tickets at representative railway stations for deciding the travel pattern with regard to season and card ticket holders.

It was observed that demand is very high during peak periods of morning and evening and low during non-peak periods. It is decided to carry out analysis for peak periods. Existing schedule of trains, number of stations, inter-station travel time etc was obtained from suburban railway timetable provided by railway authorities. Monthly sale of season tickets to different destinations was provided by booking office at each railway station. Shift wise sale of card tickets was also obtained from ticket sale offices at each railway stations. There are four shifts for sale of card tickets namely: 0.00 to 07.00, 07.00 to 14.00, 14.00 to 21.00 and 21.00 to 24.00. According to variation of traffic with time in a day four different periods are identified and mean arrival rates are decided for each period at different stations. Similarly mean number of passengers getting down different stations is also obtained. From shift wise sale of tickets it was difficult to identify the percentage of commuters with card tickets. To fix the actual percentages, hourly sale of tickets is noted for five days from counters at five representative stations: Beach, Park, Mambalam, Guindy, Pallavantangal and Tambaram stations. From noted details of hourly sales, average percentage of commuters using card tickets during peak hours in either direction were calculated. Following groups for fixing the percentage during morning and evening peak periods were formed.

- *TBM*, TBMS, CMP, PV
- TLM, MN, *PZA*
- STM, *GDY*, SP
- *MBM*, NBK, KBK, MSC
- MS, *MP*
- MF, *MB*

Different peak and non-peak periods based on the travel pattern are as follows:

For Tambaram to Beach direction
i) 04.00 to 06.30: Non peak period
ii) 06.30 to 07.30: Transition period
iii) 07.30 to 10.00: Peak period (Morning)
iv) 10.00 to 24.00: Non- peak period

For Beach to Tambaram direction
i) 04.00 to 16.00: Non peak period
ii) 16.00 to 17.00: Transition period
iii) 17.00 to 19.30: Peak period (Evening)
iv) 19.30 to 24.00: Non peak period

During transition period the mean arrival rate is higher than non-peak period but less than peak period. It was found from surveys that 80% season ticket holders travel during peak periods from various stations. Traffic surveys were conducted at selected railway platforms to study arrival pattern. It is found that during a particular period uniform number of passengers arrive to board the train. Thus mean arrival rate for each railway station was decided for peak periods. Travel pattern indicated that maximum number of commuters (41,994) travel between Kodambakkam and Nungambakkam. Similarly approximately 41, 966 passengers travel between Kodambakkam and Mambalam during evening peak period. Number of trains during morning peak period is found to be 23. Thus each train carries above 1800 passengers, which is three times the train capacity (600 seating capacity of MG suburban trains). Similar pattern was observed for evening peak period. It is evident from the travel pattern that trains were overcrowded during morning and evening peak periods. In view of this the morning and evening peak periods were considered for analysis

Simulation Model

Digital simulation may be defined as numerical technique for conducting experiments on digital computer with certain type of mathematical and logical models, which describe the behavior of the complex system over extended period of real time. When it is decided to simulate, the experimental nature of the simulation technique makes it essential to plan the study by deciding upon the major parameters to be varied, the number of cases to be conducted and the order in which runs are to be made. The study under consideration involves simulation of train transit network to check the interaction between sub-models. The simulation model for suburban train operation describes behavior of trains and passengers as they move over the network. The simulation of operation on the network is carried out in two parts. In first part, the flow of passengers and trains is in one direction (Tambaram to Beach) where as in second part the flow is in the opposite direction (Beach to Tambaram), the flow for one part is complement to that on the other.

In the present problem the simulation system comprises three members: passengers, train and Interaction between train and passengers. In the first phase passengers arrive at different stations per unit of simulation time, according to predetermined arrival pattern. They go on accumulating till a train comes. The second member is train, which runs from one station to another with fixed schedule. It stops at predetermined station. The starting times, reaching times at stations and trip end times are predetermined and given as input to simulation model. The third element is an abstract system; the interaction between train and passengers is main event. Depending on the available capacity of train people will enter the train and others have to wait. The queues that are formed are of continuous nature. 30 seconds is taken as simulation clock unit so it is assumed that people arrive in bunches every 30 seconds as per predetermined arrival pattern. Such similar bunches keep on adding to the queues at railway stations in every 30 seconds. So at every railway station a queue is formed and single queue single server FIFO (first in first out) pattern is observed. Abstract data type which group the data types into different data object depending upon the types of operation are widely used in this program. The simulation program is written in 'C' language. The different types of data structure used in this program are queues and link list implementation. The numbers of trains running between two extreme stations are more in the peak period and less in the non-peak period. Therefore queue implementation for trains is used in analysis. The contents of

train queue element are previous- station, next-station, train number, present-station number and number of passengers traveling. These elements are updated after every simulation time unit. A train having reached at a station is identified when its previous station and next station numbers are same. When a train reaches at its destination that train is deleted from the queue. A fast service train departed after normal train (stopping at all stations) may be terminated early due to overtaking operation. The arrival of passengers is connected to the station. Passengers accumulate on the platform and queue formation takes place at every station. Hence linked list implementation is found to be more useful connected with adjacency list. Each station has two linked lists. The first one is for arrival of passengers. The numbers of passengers with their arrival times are the elements. When train reaches at a particular station people start moving in a queue, enter into the train and delay group is identified. When a train arrives delay of each group of people is updated. As soon as people enter the train delay elements are formed provided there is no other element with the same delay unit. A search is made through the element list to find out whether any element is there with the same delay time. If not a new element is formed otherwise, its location will be formed and numbers of people are added to that element. Thus there cannot be two elements with the same delay units. Therefore at any time it is known how many people waited for how much time units. If a group of people enters into the train then that element is deleted from the list. There is no delete process for delay

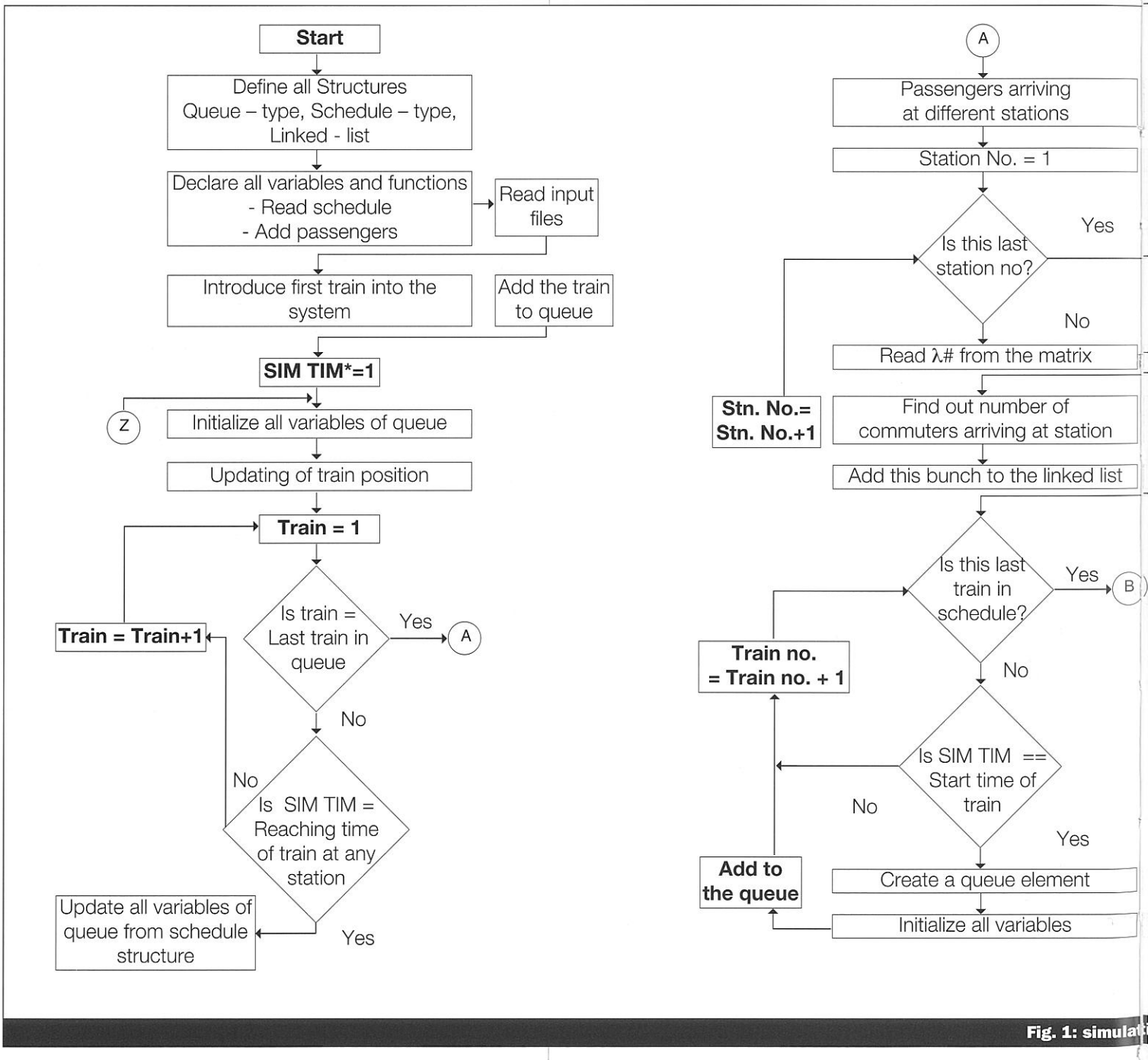


Fig. 1: simulat

elements. If the capacity of train becomes full, the remaining people in a group have to wait for the next train to come. Figure 1 shows the flow chart of entire simulation process. The different steps involved in the program, are as follows:

(i) Passengers arrive at platform
(ii) Passengers board
(iii) Train leaves the station '1' (say TBM)
(iv) Update train load
(v) Train arrive at station '2' (say TBMS)
(vi) Passengers alight
(vii) Check the capacity of train
(viii) Passengers board as per capacity
(ix) Train leaves station '2'
(x) Update train load
(xi) Train arrives at station '3' (say CMP)
(xii) Steps continue till train reaches last station

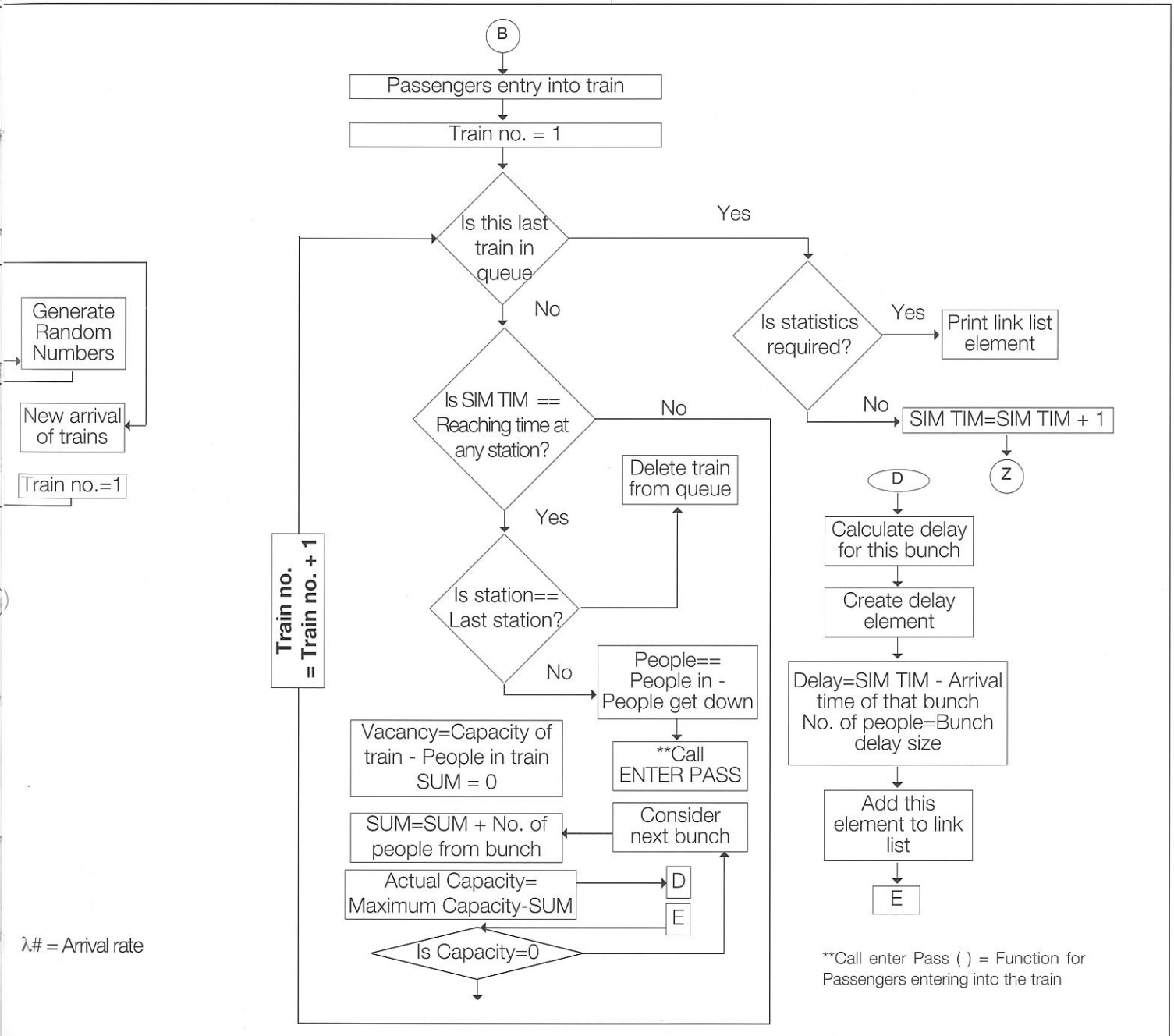
Inputs to the Model

All input times are given in terms of simulation clock unit of 30 seconds. Following are the input parameters of the simulation model.

(i) Schedule of trains. (ii) Stopping station sequence of trains.

(ii) Data file containing train number, starting station, starting time and number of stopping stations.

(iii) Average hourly variation of arrival pattern people at each station. It has been expressed as number of commuters arriving at the end of every 30 seconds interval.



ion flow chart

(iv) Average hourly variation of alighting pattern at each station. It is expressed in terms of a percentage of loading level in train on arrival. Loading level of train varies as it proceeds from one station to another. If loading level of train is more then more number of commuters will alight as per average percentage assigned to that particular station.

Output of the Model

Following are the output values obtained from the model.
(i) The status of train before reaching a station and at station, number of people boarding and
alighting on a particular train.
(ii) Delay experienced by passengers at all stations under consideration.

Validation of Simulation Model

Validation of simulation model was done using average waiting time of passengers and boarding, alighting and onboard pattern at each station. Towards MSB during morning peak period the difference between observed and simulated values for boarding pattern was found to be 0.47% to 21%, for alighting pattern0.7% to 24% and for onboard passengers 0.47 to 5.5%. Figures 2, 3 and 4 show the comparison between observed and simulated values of boarding, alighting and onboard patterns towards MSB direction. Similarly towards Tambaram also similar figures are plotted (Shrivastava, 1993). Towards Tambaram during evening peak period difference between observed and simulated values were found to be for boarding: 1% to 27%, for alighting: 3.8% to 7.7% and for onboard: 3.5% to 7.7%. Thus the difference between observed and simulated values ranges between 0.47 and 27 percentage. Also the average waiting time at different stations varies from 3.4 to 12 minutes. For the given schedule of trains the headway varies from 5 to 13 minutes. It is observed that passengers do take the trains without worrying about crowding level and safety without waiting for another train in the queue. Thus the average waiting time obtained by the model is well within the expected range.

Results

The simulation model developed for train operation is used to study following alternatives:
a) Train movement as per existing schedule with a maximum capacity of 1500 (2.5 times the seating capacity, 600) per train.
b) Train movement with different average headways ranging from 5 minutes to 9 minutes with maximum capacity of 1500 passengers per train.
c) Increasing the capacity by running all trains with 9 coaches (seating capacity: 700 and maximum capacity: 1750, 2.5 times of seating capacity) and with varying average headways from 5 minutes to 8 minutes.
In the analysis of the above alternatives the schedule of services of fast trains (which do not stop at some stations) and cut trains (trains which are reversed back from intermediate stations) are kept as per the existing schedule. Following results are obtained by simulation model:
1) With existing frequency of trains and limiting capacity to 1500, the average passenger waiting times are 17.27, 17.08, 12.18 and 10.51 minutes at MKK, SP, STM and MBM stations respectively for morning peak periods (refer fig. 5) and 16.95, 15.35, 14.05 and 13.5 minutes for MSC, MS, MKK and NBK stations respectively during evening peak period (refer fig. 6). At other stations waiting time is with in 10 minutes
2) With existing schedule and for maximum capacity of 1500, more number of trains will run with full load resulting higher waiting times at above stations. It is evident from table 1 that percentages of trains arriving with full capacity are 75, 79, 85 and 95 at SP, MBM, MKK and NBK stations respectively during morning peak period. Table 2 shows that for evening peak period the values are 84, 95.5, 89.5 and 89 at MS, MSC, NBK and MKK stations respectively. At 5 minutes average

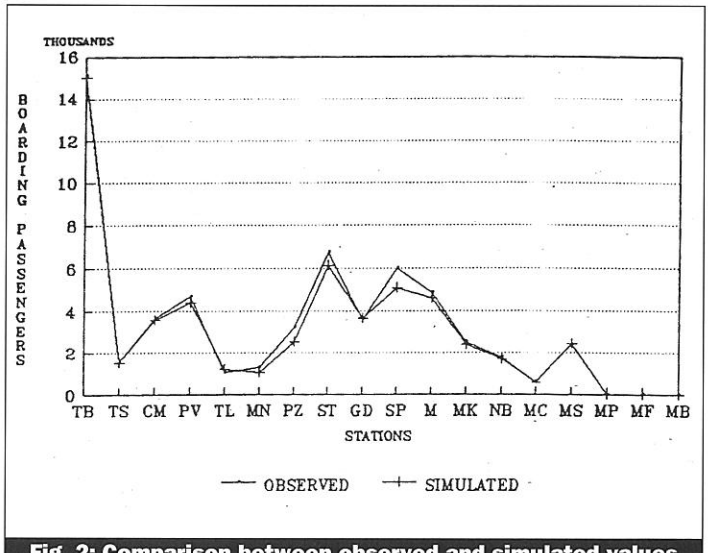


Fig. 2: Comparison between observed and simulated values (boarding pattern) Tambaran to Beach direction, Morning peak period (7.30-10 hrs)

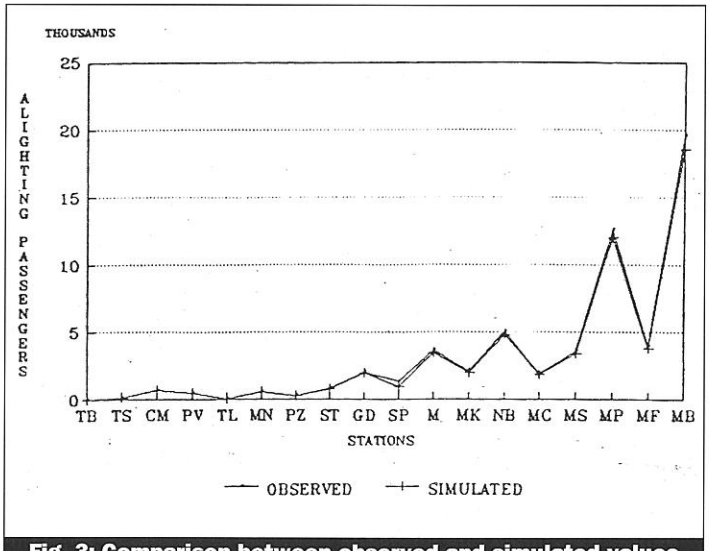


Fig. 3: Comparison between observed and simulated values (alighting pattern) Tambaran to Beach direction, Morning peak period (7.30-10 hrs)

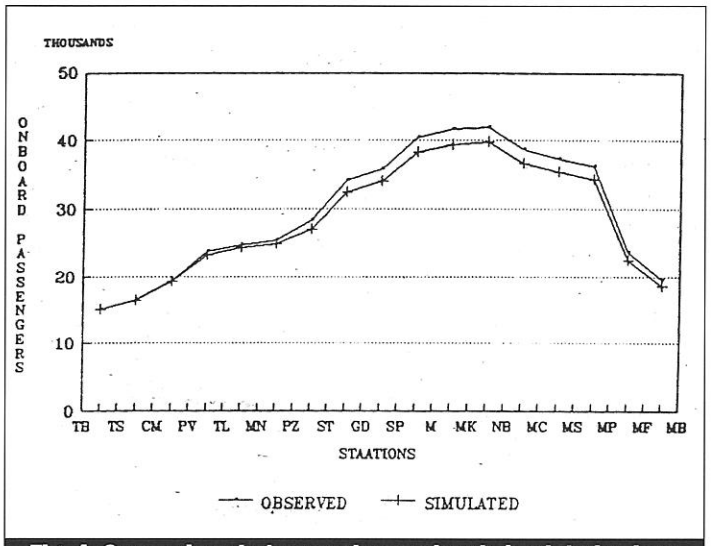


Fig. 4: Comparison between observed and simulated values (onboard pattern) Tambaran to Beach direction, Morning peak period (7.30-10 hrs)

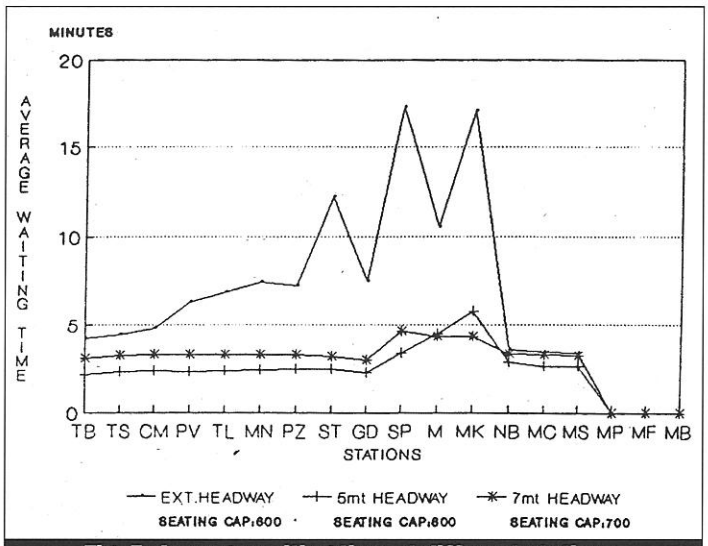


Fig. 5: Average waiting time at different stations, Tambaram to Beach direction Morning peak period (7.30-10.00 hrs)

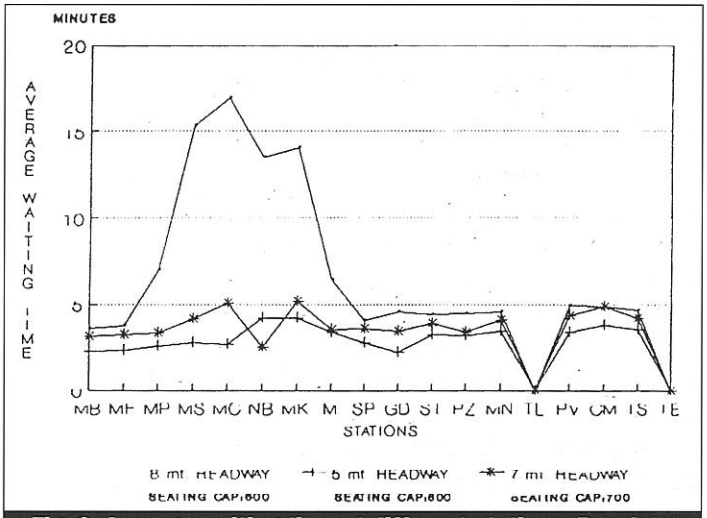


Fig. 6: Average waiting time at different stations. Beach to Tambaram direction Evening peak period (7.30-10.00 hrs)

headway the percentage of full capacity trains will be zero at all stations except 10, 20 and 23 percentage trains will have full load at MBM, MKK and NBK stations during morning peak period, while during evening peak period the values are 6.8, 6.8, 10.7, 14.3, 17.8 and 18.5 at MS, MSC, NBK, MKK, MBM and SP stations respectively.

3) If the headway is decreased to 5 minutes the average waiting time at all stations will be less than 6 minutes during both peak periods. By operating all as 9 coach trains (seating capacity 700), even with 7-minute average headway average waiting time at all the stations will be less than 6 minutes.

4) At 5-minute headway with 8 coach trains at all stations more than 70 % people will be able to get trains with in 10 minutes of waiting. Similarly with 7 minute headway and with 9 coach trains more than 80% commuters will be able to get trains within 10 minutes of waiting during morning peak period in TBM – MSB direction. Similarly for MSB-TBM direction, evening peak period, at 5 minute headway with 8 coach train more than 80% commuters will get train with in 10 minutes of waiting. By using 9 coach trains at 7 minute headway more than 90% commuters will get train with in 10 minutes of waiting. Table 3 shows typical values for details of waiting time, percentage of passengers boarding for different headway in TBM – MSB direction during morning peak period. Table 4 shows values corresponding to evening peak period in the reverse direction.

Conclusions

The developed simulation model predicts that for Madras Beach – Tambaram meter gauge railway line for existing travel pattern and to restrict loading level up to 2.5 times the seating capacity instead of operating trains with existing schedule (headway between 5 to 13 minutes), it is better to run trains at uniform headway of 5 minutes. If seating capacity of all the trains is increased to 700 then for 2.5 times loading level trains can be run at 7 minutes headway. In both cases more than 70% passengers will be able to get trains in less than 10 minutes of waiting and average waiting time will be less than 6 minutes at all the stations.

The developed simulation model can be effectively used by railway agencies for development of train schedules for the given demand. Including randomness in train movement and passenger detraining pattern can further refine the model.

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Stations	Existing Headway 5-13 minutes			Average Headway 8 minutes			Average Headway 7 minutes			Average Headway 6 minutes			Average Headway 5 mts		
	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %
TBM	20	00	00	23	00	00	25	00	00	27	00	00	33	00	00
TBMS	17	00	00	19	00	00	21	00	00	24	00	00	30	00	00
CMP	17	00	00	19	00	00	22	00	00	24	00	00	30	00	00
PV	17	02	12	19	00	00	21	00	00	24	00	00	29	00	00
TLM	18	05	28	20	00	00	22	00	00	24	00	00	30	00	00
MN	17	05	30	19	00	00	21	00	00	25	00	00	29	00	00
PZA	17	07	41	19	00	00	21	00	00	25	00	00	28	00	00
STM	20	08	40	22	00	00	23	00	00	26	00	00	29	00	00
GDY	24	14	58	25	15	60	27	11	40	30	00	00	34	00	00
SP	20	15	75	22	11	50	24	08	33	27	00	00	31	00	00
MBM	24	19	79	25	19	76	27	22	81	30	17	56	37	04	10
MKK	21	18	85	22	19	86	24	19	79	27	17	62	30	06	20
NBK	20	19	95	23	21	91	22	22	100	26	19	73	30	07	23
MSC	21	00	00	22	00	00	24	00	00	27	00	00	30	00	00
MS	24	00	00	24	00	00	27	00	00	29	00	00	33	00	00
MPK	23	00	00	23	00	00	25	00	00	28	00	00	31	00	00
MSF	23	00	00	24	00	00	25	00	00	28	00	00	31	00	00

No. of trains: Total number of trains frequenting station during peak period
Full capacity trains: Total number of trains frequenting with full capacity before reaching to station.

Table 1: Trains running with full capacity (1500) with different headways at different stations during morning peak period (7.30 – 10 hrs), Tambaram – Beach direction

Waiting Time. minutes	Boarding Passengers (%)																			
	STM				GDY				SP				MBM				MKK			
	Headway, minutes				Headway, minutes				Headway, minutes				Headway, minutes				Headway, minutes			
	Exis -ting	08	07	06	Exis -ting	08	07	06	Exis -ting	08	07	06	Exist - ing	08	07	06	Exist ing	08	07	06
00 – 05	60	64	78	86	56	57	80	88	33	31	58	85	57	53	61	85	37	30	62	83
00 – 10	89	98	100	100	89	88	100	100	59	55	94	100	94	91	91	100	79	72	95	100
00 – 15	100	100	-	-	100	100	-	-	79	76	100	-	100	100	100	-	97	97	100	-
00 – 20	-	-	-	-	-	-	-	-	92	86	-	-	-	-	-	-	100	100	-	-
00 – 25	-	-	-	-	-	-	-	-	97	93	-	-	-	-	-	-	-	-	-	-
00 – 30	-	-	-	-	-	-	-	-	100	100	-	-	-	-	-	-	-	-	-	-

Table 3: Waiting time and percentage of passengers boarding the trains with different headways, morning peak period, Tambaram to Beach direction (Seating Capacity = 700)evening peak period (17.00 – 19.30 hrs), Beach - Tambaram direction

Stations	Average Headway 8 minutes.			Average Headway 7 minutes			Average Headway 6 minutes			Average Headway 5 minutes		
	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %	No. of trains	Full Capacity trains	Full Capacity trains, %
MSB	19	00	00	21	00	00	26	00	00	31	00	00
MSF	18	00	00	22	00	00	26	00	00	30	00	00
MPK	20	00	00	22	00	00	26	00	00	30	00	00
MS	19	16	84	23	18	78	26	11	42	29	02	07
MSC	18	17	95	19	18	94	24	13	54	29	02	07
NBK	19	17	90	21	18	86	24	12	50	28	03	11
MKK	18	16	89	20	17	85	24	12	50	28	04	14
MBM	19	17	90	21	20	95	25	17	68	28	05	1819
SP	18	16	89	22	16	73	24	14	58	27	05	00
GDY	19	01	05	21	01	05	25	00	00	26	00	00
STM	18	00	00	20	00	00	24	00	00	26	00	00
PZA	17	00	00	18	00	00	22	00	00	26	00	00
MN	17	00	00	19	00	00	22	00	00	24	00	00
TLM	17	00	00	18	00	00	22	00	00	24	00	00
PV	16	00	00	19	00	00	22	00	00	24	00	00
CMP	17	00	00	19	00	00	22	00	00	24	00	00
TBMS	16	00	00	17	00	00	22	00	00	24	00	00

No. of trains: Total number of trains frequenting station during peak period
Full capacity trains: Total number of trains frequenting with full capacity before reaching to station.

Table 2: Trains running with full capacity (1500) with different headways at different stations during evening peak period (17.00 – 19.30 hrs), Beach - Tambaram direction

Waiting Time. Minutes	Boarding Passengers (%)											
	MPK			MS			NBK			MBM		
	Headway, minutes			Headway, minutes			Headway, minutes			Headway, minutes		
	Exis -ting	08	07	Exis -ting	08	07	Exis -ting	08	07	Exist - ing	08	07
00 – 05	24	29	75	49	41	69	49	40	61	57	48	72
00 – 10	75	68	100	79	75	95	72	65	91	93	90	100
00 – 15	94	90	-	94	88	100	89	80	100	100	100	-
00 – 20	100	100	-	100	100		100	100	-	-	-	-

Table 4: Waiting time and percentage of passengers boarding the trains with different headways, evening peak period, Beach to Tambaram direction (Seating Capacity = 700)