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Application Of Genetic Algorithm For Scheduling And Schedule Coordination Problems

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The problems on scheduling and schedule co-ordination usually have conflicting objectives related to user's cost and operator's cost. Users want to spend less time to wait, transfer and travel by public buses. Operators are interested in profit making by lesser vehicle operating cost and having a minimum number of buses. As far as level of service is concerned users are interested in lesser crowing while operators are concerned with maximizing profit and thus to have higher load factors. In schedule co-ordination problems transfer time plays an important role. Users are interested in coordinating services with in acceptable waiting time whereas operators prefer to have lesser services and want to meet higher demands, which invariably increases waiting time. These problems have multiple conflicting objectives and constraints. It is difficult to determine optimum solution for such problems with the help of conventional approaches. It is found that Genetic Algorithm performs well for such multi objective problems.

Introduction

The non-linear mathematical programming is being used in various engineering optimization problems. Most existing algorithms for solving non-linear programming problems are generally gradient based, and require at least the first order derivatives of both objective and constraint functions with respect to the design variables. With the "slope tracking"

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ability, gradient-based methods can easily identify a relative optimum closest to the initial guess of the optimum design however there is no guarantee of locating the global optimum if the design space is known to be non-convex. In such cases exhaustive and random search techniques like random walk or random walk with direction exploitation are quiet useful. The biggest drawback with these methods is that often they require thousands of function evaluations, even for simplest functions to achieve the optimum. Genetic Algorithms (GAs) proposed by Holland (1975) are based on exhaustive and random search techniques, found to be robust for optimizing non-linear and non-convex functions. In this paper models for scheduling and schedule co-ordination of public buses are developed and the objective functions with constraints are optimized by Genetic Algorithm.

The first study deals with the *scheduling problem*. In most of the approaches development of routes and selection of frequencies of buses is done separately to avoid complications and computational burden. In actual practice both go hand in hand. If routing and scheduling go together the generated routes support the defined schedule. The study discussed in this paper deals with the simultaneous routing and scheduling. In this study objective function of scheduling model is taken as minimization of users and operators costs. Users costs are waiting time for public buses, transfer time from one bus to another and in vehicle travel time whereas operators cost is vehicle operation cost. These two are conflicting objectives in the sense that if more buses are run waiting time will be reduced but fleet size increases and thus the vehicle operating cost would increase. Moreover load factor (crowding level in bus) is also of great concern to users and operators. Lower the load factor better will be level of service but from operators point of view it may not be economical. Therefore at least the minimum break-even load factor has to be met. Various links on routes have certain maximum capacities. In case of overlapping routes buses of different routes pass through the same link. Thus maximum number of buses passing through a particular link should be less than its capacity. Apart from these constraints bus operating agencies have to meet the objectives with certain given fleet size of buses. In *schedule co-ordination* problems apart from above objectives and constraints transfer time between two modes also plays an important role. From users point the coordinating services should be available with in certain minimum acceptable transfer time whereas operator has to ensure that desirable number of commuters are available for coordinating services so as to meet minimum acceptable load factor. In both the problems the attempt should to be made to satisfy maximum demand. Thus both the problems are multi objective and involve large number of variables and constraints. Development of optimal schedules is an extremely difficult task even for small transit network (Kikuchi and Parmeswaran, 1993). The difficulty arises because of large number of variables and constraints. The discrete nature of variables and non-linearity involved in the objective function and the constraints further increase the complexity and computational burden. . Chakroborty et al. (1995) highlighted the enormity of the similar type of problem. Even after linearizing the problem the complexity remains very large. The benefit obtained through linearization is offset by the increase in the number of variables and constraints. In general, the number of variables and the number of constraints required are of the order of $O\ (r^2n^2)$, where r is the number of routes through a transfer station and n is the number of buses/trains on any of the routes. Chakroborty et al. attempted to solve the linearized formulation of similar problem but the algorithm failed to converge to any solution. Based on this experience and that reported for a similar problem elsewhere (Kikuchi and Parmeswaran 1993), it is decided to use simple Genetic Algorithm for both scheduling and schedule co-ordination problems. LibGA package on Genetic Algorithm is used for optimization (Lance Chambers, 1995). Brief discussion on Genetic Algorithm is provided in Appendix-I of this paper.

Models For Scheduling And Schedule Co-Ordination

Scheduling Model

The model mainly attempts to address the problem of simultaneous selection of routes and schedules and hence to find optimal fleet size on an optimally designed routes. As discussed user costs is taken as total travel time, which includes in-vehicle travel time, waiting time and the transfer time. Any transfer in the network is discomfort to commuters and hence appropriate penalty in terms of travel time is adopted for transfers. For our case study this penalty is adopted as 5 minutes. The operator cost is taken as running time cost of the buses. The objective function is minimization of summation of both users and operators costs. Constraint for load factor is taken for better level of service and economical operation. Fleet size constraint is adopted to keep the number of buses under certain specified limit. Link overloading constraint ensures that there cannot be more buses over maximum capacity of any link under consideration. Penalty method of constraint optimization is adopted as discussed earlier. Thus due to violation of any constraint appropriate penalty is adopted as per their relative importance (Gundaliya, 1999). The penalties are added to objective function and penalized objective function is obtained. Weights to the penalties are given in terms of function of objective function value as per their relative importance. Penalties are applied for unsatisfied demand, one transfer, violation of minimum and maximum load factors, fleet size and link over loading. The optimal routes and schedules will be corresponding to minimum penalized objective function. For this model routes and schedules are variables which are coded together, means a binary string for application of Genetic Algorithm contains two sub strings one represents route and other frequency on that route. Finally after implementing GA optimal set of strings are obtained which indicate set of routes and corresponding frequencies. The model is tested for Mandl's Swiss transit network and demand matrix (Mandl, 1980 and Baaj et al., 1990).

The mathematical formulation of the problem is as follows.

Objective Function

$$Minimize\left\{C_1\times\left[\sum_{j=1}^{n}\sum_{i=1}^{n}d_{ij}\times t_{invt_{ij}}\right]+C_2\times\left[\sum_{j=1}^{n}\sum_{i=1}^{n}d_{ij}\times t_{wt.ij}\right]+C_3\times\left[\sum_{j=1}^{n}\sum_{i=1}^{n}d_{ij}\times t_{tt.ij}\right]+C_4\times\left[\sum_{all\,k\in SR}f_k\times t_k\times T\right]\right\} \quad (1)$$

Subject to

$$\frac{Q_{k.\max}}{N_k\times CAP}\le L_{\max} \quad \text{(Maximum load factor constraint)} \quad (2)$$

$$\frac{Q_{k.\max}}{N_k\times CAP}\ge L_{\min} \quad \text{(Minimum load factor constraint)} \quad (3)$$

$$\sum_{all\ k\in SR}NB_k=\left[\sum_{all\ k\in SR}\frac{N_k\times(RT)_k}{TP}\right]\le W \quad for\ all\ \ k\in SR$$

(Fleet size constraint) (4)

$f_{ij}\le F_{\max}$ (Link overloading constraint) (5)

Where,

C_1 = Cost of in-vehicle time per minute (adopted as Rs. *0.22* per minute for case study from MMPG, 1997)
C_2 = Waiting time cost per minute (adopted as Rs. 0.15 per minute for case study from MMPG, 1997)
C_3 = Transfer time cost per minute (adopted as Rs. 0.15 per minute for case study from MMPG, 1997)
C_4 = Bus operation cost per minute (Rs. *6.8* per minute from BEST, 1999)
i and j = nodes
n = Number of nodes
d_{ij} = Demand between nodes i and j
$t_{invt.ij}$ = In-vehicle time between nodes i and j in minutes
$t_{wt.ij}$ = Waiting time incurred while travelling between nodes i and j, minutes
$t_{tt.ij}$ = Transfer Time (penalty per transfer)for trips between i and j, minutes
SR = Set of routes
f_k = Frequency of buses on k^{th} route in terms number of buses per hour
t_k = Travel time on route k, hours
T = Time period, hours
$Q_{k.max}$ = Maximum number of passengers on k^{th} route during time period T
N_k = Number of trips during entire period on k^{th} route i.e. number of trips per hour times period in hour $(f_k \times T)$
CAP = Capacity of public bus (seating capacity as *54*)
L_{max} = Maximum allowed load factor (For the case study *1.2*)
L_{min} = Minimum allowed load factor (For the case study break even load factor *1.12)*
NB_k = Number of buses required in any route k.
RT_k = Round trip time of the bus on k^{th} route in minutes = $2t_k$ (in minutes) + lay over time (*5* minutes for the case study)
TP = Time Period in minutes
W = Maximum number of available buses
f_{ij} = frequency of buses on link i-j

$$f_{ij} = f_k \text{ (if link } i\text{-}j \text{ belongs to only one route } k\text{)} \quad (6)$$

$$f_{ij} = \sum_{k=1}^{k=R} f_k$$

(if R are number of routes passing through i-j) (7)

F_{max} = Maximum allowable frequency on link i-j

Steps Involved for Model Development

1) Inputs like number of nodes in the network, travel time matrix, demand matrix and other design parameters such as seating capacity, maximum and minimum load factors, fleet size and distribution factor etc. are determined.
2) Node pairs with more than above average production & attraction are selected and K-shortest paths are generated between above identified node pairs.
3) Paths between node pairs having lengths between *15* to *33* minutes and more than Average Route Flow Value (*ARFV*) are selected.
4) Each alternative paths are considered and traffic load is assigned based on exponential function of frequency and distance (Gundaliya, 1999)
5) The demand d_{ij} is assigned on the links on the path followed by the transfer. The waiting time at transfer point ($t_{wt\cdot ij}$) is calculated based on frequencies on routes before and after transfer.
6) Total travel time is calculated as

$$t_{ij} = t_{invt.R1} + t_{invt.R2} + t_{wt.ij} + \text{Transfer penalty} \tag{8}$$

Where,

$t_{invt.R1}$ = In-vehicle time from node i to transfer point through route R_1

$t_{invt.R2}$ = In-vehicle time from transfer point to node j through R_2 route

7) The program for fitness is developed in object-oriented environment in C++. The node, link and routes are different classes designed to handle complexity of problem. Arrays of designed class objects are created using dynamic memory allocation. These features of software enables to handle large size of network.
8) Genetic Algorithm is implemented and optimal routes and corresponding set of frequencies are obtained. The implementation of GA is discussed ahead separately.
9) Required numbers of buses are calculated from optimal frequencies obtained by Genetic Algorithm.

Development of Schedule Optimization Model (SOM) for Co-ordination

This model is developed to co-ordinate the schedules of public buses with the existing schedules of suburban trains. In this model suburban trains are considered as main line haul service and public buses are considered as feeder services. The purpose of schedule co-ordination is to ensure that feeder bus services are available within minimum acceptable transfer time after arrival of trains. In this case also there are conflicting objectives because train commuters prefer coordinating buses with in acceptable waiting time where as bus operators prefer to meet maximum demand with least number of buses, which invariably increases transfer time. The constraints regarding load factor as discussed in the earlier model is true in this case also. Andheri and Vileparle suburban railway stations in Mumbai, India are taken as study areas and Bombay Electric Supply and Transport (BEST) buses are considered as feeder services. Coordinated schedules of BEST buses are developed for the existing schedules of suburban trains at these railway stations. Both the stations have eastern and western areas on both sides of railway line. The feeder routes were developed for these stations for both eastern and western sides. There are 11, 7, 8 and 5 feeder routes for Andheri (E), Andheri (W), Vileparle (E) and Vileparle (W) (Shrivastava and Dhingra, 2001). The coordinated schedules are developed for BEST buses for these feeder routes. Penalty method of constraint optimization is adopted for this model also i.e. due to violation of any constraint, appropriate penalty is calculated and added to objective function and thus penalized objective function is determined. The objective function for schedule optimization model is taken as minimization of distance traveled by buses (operator's cost) and transfer time between bus and train (user's cost). Optimal sets of frequencies are calculated through Genetic Algorithm. Penalized objective function is minimum for the optimal set of frequencies.

Mathematically, the objective function and various constraints are as follows: -

<u>Objective Function</u>

Minimize

⟵ *Transfer Time between up and down trains and buses* ⟶ ⟵ *VOC* ⟶

$$C_1 \left\{ \sum_j \sum_u \sum_l p_j^u (d_j^l - a^u)\, \delta_j^{u.l} + \sum_j \sum_u \sum_l p_j^v (d_j^l - a^v)\, \delta_j^{v.l} \right\} + C_2 \left\{ \sum_j f_j T l_j \right\} \qquad (9)$$

Constraints:

$(d_j^l - a^u) \le T_{max}$ and $(d_j^l - a^v) \le T_{max}$
(Maximum transfer time constraint) (10)

$(d_j^l - a^u) \ge T_{min}$ and $(d_j^l - a^v) \ge T_{min}$
(Minimum transfer time constraint) (11)

$$\frac{Q_{j.\max}}{N_j \times CAP} \le L_{\max}$$
(Maximum load factor constraint) (12)

$$\frac{Q_{j.\max}}{N_j \times CAP} \ge L_{\min}$$
(Minimum load factor constraint) (13)

$$\sum_j d_{unsat} = 0$$
(Unsatisfied demand constraint) (14)

Where,

j = Number of routes available at each stations
l = Number of buses available for 'u' up trains and 'v' down trains.
VOC = Vehicle operating cost
C_1 = Cost of transfer time in Rupees per minute. Adopted as Rupees 0.15/minute for the case study, (MMPG, 1997)
C_2 = Cost of operation of BEST bus per Km.. Adopted value is Rupees 31.37/Km for the case study (BEST, 1999)
p_j^u = Passengers transferring from u^{th} up train to j^{th} route.
p_j^v = Passengers transferring from v^{th} down train to j^{th} route.
d_j^l = Departure of l^{th} bus on j^{th} route at railway station.

a^u = Arrival of u^{th} up train at railway station

a^v = Arrival of v^{th} down train at railway station

$\delta_j^{u.l}$ = is a term which shows whether transfer of passengers is possible or not. It attains a value one if transfer from u^{th} up train to l^{th} bus on j^{th} route at railway station is feasible otherwise it attains a value zero.

$\delta_j^{v.l}$ = is also a term which shows whether transfer of passengers is possible or not. It attains a value one if transfer from v^{th} down train to l^{th} bus on j^{th} route at railway station is feasible otherwise it attains a value zero.

f_j = Frequency of buses on j^{th} route in terms of number of bus trips per hour.

l_j = length of j^{th} route in kilometers

TP = Time period, hours

T_{max} = Maximum allowable transfer time between arrival of train and departure of connecting bus. For the case study this value is assumed as 10 minutes (Based on commuters opinion survey in study area).

T_{min} = Minimum allowable transfer time between arrival of train and departure of connecting bus. For the case study this value is assumed at 5 minutes (Based on observations and opinion survey of commuters in study area).

$Q_{j.max}$ = Number of passengers on first link connecting railway station on j^{th} route for the given time period.

N_j = Number of bus trips during entire time period under consideration($f_j \times TP$)

CAP = Seating capacity of bus (taken seating capacity as 54)

L_{max} = Maximum load factor (For the case study this value is taken as 1.2 which is based on commuters opinion survey)

L_{min} = Minimum load factor (For the case study this value is taken as 1.12, which is break even load factor of BEST)

d_{unsat} = Unsatisfied demand (Number of passengers who could not get bus)

The first term of objective function indicates transfer time between suburban trains (both up and down trains) and coordinating buses. The second term is vehicle operating cost, which is proportional to distance traveled by buses. Constants $C_1$and C_2 are used to convert objective function in monetary unit of Rupees. The first constraint ensures that transfer time between arrival of a train and departure of connecting buses should be less than a maximum value. This constraint is imposed because if coordinating bus is available after the acceptable maximum waiting time (after arrival of train) the passengers will be uncomfortable due to delay. Therefore this constraint ensures that coordinating buses are available within acceptable maximum transfer time (waiting time) after arrival of train. Any transfer after maximum waiting/transfer time is penalized in optimization process and the penalty increases with increase in transfer time so that coordinating buses are available with in acceptable limit of waiting or with least delay. The second constraint ensures that there should be minimum time available for transfer. This constraint is obvious because it takes some minimum walk time for passengers to approach bus stops and board coordinating buses after alighting from trains. The third and fourth constraints ensure that the load factor lies within a maximum and a minimum value so that appropriate level of service and availability of a certain minimum number of passengers can be ensured for economical operations. The last constraint ensures that maximum demand is satisfied and maximum numbers of commuters get coordinating buses. None of the above constraints are rigid. These constraints are obeyed and violated as per their relative importance and magnitude is directly proportional to potential demand associated with a particular constraint (Shrivastava, 2001). Number of buses for each route is calculated as given in the earlier model.

Implementation of Genetic Algorithm for the Case Studies

The Genetic Algorithm parameters like pool size, crossover probability, mutation probability, seed value etc are decided after several runs for the proposed objective function. It was found that roulette selection, uniform crossover, simple random mutation and seed value '*1*' gave better results (Shrivastava, 2001). Thus optimum pool size, crossover and mutation probabilities are determined for above combination. Following are the optimum parameters for the objective functions under consideration.

	Scheduling problem	**Schedule coordination problem**
Pool size	40	420
Cross over probability	0.95	0.80
Mutation probability	0.1	0.01

Scheduling Problem

The program for penalized objective function is prepared in C++ environment. With this program for the given set of routes and frequencies, penalized objective function is calculated. Random sets of routes and frequencies generated by Genetic Algorithms were given as input to the objective function program and the set of routes and frequencies for which the value of penalized objective function is minimum is selected as optimal routes and frequencies. Binary coding for routes and corresponding frequencies is adopted. Routes and the frequencies for each pair are coded into a single string with the desired precision (Goldberg, 1989). For example fig. 1.0 shows binary digits coding for route number 5 and route number 3 with frequencies 6 and 21. First four bits show route and last six bits show corresponding frequency in a string. The model developed here is tested on the Mandl' s Swiss network of fifteen nodes. Mandl (1980) originally reported this benchmark network. The same network also used by Baaj et al. (1990). An average speed of the bus 15 km/hr. is adopted for calculation.

Schedule Coordination Problem

The developed model is tested for Andheri and Vileparle suburban railway stations in Mumbai, India and schedule co-ordination is attempted for BEST buses for existing schedules of suburban trains at these railway stations. Penalty method of constraint optimization is attempted for this case also. The results obtained by Genetic Algorithm are very sensitive to penalties. Slight variations in penalties show wide variation in results, in view of this the final penalties are decided after many trials using their different combinations and their relative importance. Following criterions are adopted for deciding appropriate penalties.

- Load factor for buses should not be excessively high or low. As discussed in earlier model higher load factor causes poor level of service and lower one is uneconomical to operating agency.
- Unsatisfied demand should not be very high. It should be as low as possible, preferably it should be zero.
- Transfer time should be with in reasonable limits.

Penalties

All the penalties are expressed in terms of percentage of objective function value and thus different values of objective function multipliers are calculated as per their relative importance (Shrivastava, 2001).

<table>
<tr><td colspan="10">Pair no 1</td><td colspan="10">Pair no 2</td></tr>
<tr><td colspan="4">Route</td><td colspan="6">Frequency</td><td colspan="4">Route</td><td colspan="6">Frequency</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td colspan="4">Route no 5</td><td colspan="6">Frequency 6</td><td colspan="4">Route no 3</td><td colspan="6">Frequency 21</td></tr>
</table>

Fig. 1.0. Binary digit coding

It has been observed that on an average it takes 5 minutes to reach to bus stop after getting down from train, thus minimum transfer time from train to bus is taken as 5 minutes. Therefore any bus, which is only after 5 minutes of schedule arrival of train, is considered as connecting bus to that particular train. Transfer time between 5 to 10 minutes is regarded as acceptable. Any transfer after 10 minutes is penalized and the penalized value is added to objective function. This penalty varies as per the number of commuters getting transferred. Thus the *penalties for transfer time* is taken as function of ratio of passengers transferred and seating capacity of bus. Higher the delay due to transfer time more will be penalty. If some passengers are not able to get any bus then it is taken as *penalty for unsatisfied demand.* To ensure availability of bus to every commuter very high value of this penalty is adopted. Break even load factor required for BEST bus for 54 passengers capacity bus is 1.12. Therefore minimum load factor is adopted as 1.12. For the consideration of better level of service a maximum load factor 1.2 is adopted. If the load factor exceeds the maximum value or if it becomes less than minimum value then different values of objective function multipliers are

taken and *penalties for violation of load factors* are calculated and added to the objective function (Shrivastava, 2001).
The objective function due to transfer from train to bus, vehicle operation cost and summation of the two, which is total objective function without penalty, are calculated. Various penalties, number of buses on each route, total number of buses required, unsatisfied demands are also calculated. These calculations are done for Andheri (E), Andheri (W), Vileparle (E) and Vileparle (W). Travel pattern at these railway stations is studied for 16 hours from 6 a.m. to 10 p.m., it was found that there are two peak periods one in the morning (8 to 11 a.m.) and other in the evening (5.30 p.m. to 8.30 p.m.). Apart from peak periods there are three non-peak periods: 6 to 8 a.m., 11 a.m. to 5.30 p.m. and 8.30 p.m. to 10 p.m. All above calculations were done for all the five periods for each location (Shrivastava, 2001).

Results and Discussion

Scheduling problem

The results obtained by the developed model are compared with the Mandl (1980) and Baaj (1990) solutions as the same network is used for analysis. Mandl gave 2 route structures and Baaj gave three route structures. Table 1 gives percentage demand satisfied along with other details for these route structures. It is evident from the table that direct demand satisfied by the developed model in all the cases are higher than the Mandl and Baaj's solutions also total travel time and the number of buses are considerably reduced. The reason is that the previous approaches are based on heuristics where as in our study the Genetic Algorithm is used for optimization. It shows that Genetic Algorithm gave better results. Moreover the developed model is capable to determine optimal routes and schedules simultaneously.

Schedule Co-ordination

With the help of Genetic Algorithm optimum value of penalized objective function is obtained and corresponding frequencies are used for finding co-ordinated schedules of BEST buses for already developed feeder routes (Shrivastava and Dhingra, 2001). Co-ordinated schedules of BEST buses are determined for Andheri (E), Andheri (W), Vileparle

(E) and Vileparle (W) for all the five periods. Typical schedules and load factors are given in Table 2 and Table 3 for Andheri (E) during 6 a.m. to 8 a.m. on 11 feeder routes. It can be seen from the table 2 that if number of commuters are considerable then coordinating bus to a particular train is also with in 5 to 10 minutes which is taken as acceptable transfer time.

Table 1. Comparison of Results with Mandl and Baaj's Solutions

Set of routes	%Demand satisfied through transfer				In-veh. Travel Time (min)	Transfer time (min)	Waiting Time (min)	Total travel time (min)	Number Of Buses
	Zero	One	Two	Un Satisfied					
1. Mandl I*	**68.78**	31.22	0.0	0.0	211210	24330	14672	250212	**128**
2. Mandl II*	**69.85**	29.97	0.17	0.0	177752	23590	17598	218940	**111**
3. Baaj I@	**78.3**	21.69	0.0	0.0	169138	16970	20007	206115	**103**
4. Baaj II@	**79.65**	20.35	0.0	0.0	166461	15915	26675	209051	**93**
5. Baaj III@	**80.88**	19.12	0.0	0.0	180620	14910	22156	217686	**100**
RESULTS OF PROPOSED MODEL									
6. ARFV 300**	**93.38**	6.62	0.0	0.0	160521	5150	18154	183825	**75**
7. ARFV 400**	**89.92**	10.08	0.0	0.0	173394	7850	16446	197690	**88**
8.. ARFV 500**	**88.89**	11.11	0.0	0.0	173616	8650	21049	203315	**88**

* Mandl I, Mandl II for two route structures, @BaaJ I, Baaj II, BaaJ III for three route structures
**ARFV : Average Route Flow Value

Above 10 minutes transfer time penalties are imposed and it keeps on increasing with higher transfer time. For example for route number 1 and 8 transfer time remains with in acceptable range also load factors attain acceptable values (near to break even load factor).

For route number 1 and 8 above 80% coordinating buses have load factors equal to break even value. For other routes some load factors are slightly less than 1 it is because the amount of commuters who opt for further journey by buses are relatively lesser and objective to provide coordinating buses prevails. As the delay increases value of penalty also increases therefore a compromise is made between load factor and delay (transfer time) as per relative importance of the penalties. It is very clear from loading of 11th route in which only 77 passengers are available

Table 2. Timetable of feeder buses, Andheri (E), 6a.m. to 8a.m

Direction	Frequency of Trains / buses	Timings of trains/buses
Up Trains (Towards Churchgate)	31	6.05. 6.08. 6.12. 6.14, 6.18. 6.24, 6.30, 6.34, 6.35. 6.39. 6.46, 6.50, 6.54, 6.57, 6.59, 7.02, 7.06. 7.08. 7.09, 7.13, 7.20. 7.25, 7.25, 7.29, 7.33, 7.36. 7.44, 7.44, 7.47. 7.53, 7.56
Down Trains (From Churchgate)	38	6.02. 6.05. 6.08, 6.15, 6.16. 6.20, 6.23, 6.26. 6.28. 6.30. 6.36, 6.40, 6.41. 6.45, 6.46, 6.48. 6.52. 6.55. 6.59, 6.59, 7.05. 7.08, 7.12, 7.16. 7.16, 7.19. 7.23, 7.26, 7.29, 7.34, 7.34, 7.39, 7.41, 7.44. 7.46, 7.47, 7.49, 7.54
Route No. 1	54	6.07, 6.11. 6.13, 6.15, 6.17,6.19,6.21,6.23, 6.25, 6.29, 6.31, 6.33, 6.35,6.37, 6.39,6.41, 6.43, 6.45, 6.47, 6.51,6.53, 6.55, 6.57, 6.59, 7.01, 7.03, 7.05, 7.07,7.09. 7.11, 7.13, 7.15. 7.17, 7.19, 7.21, 7.23, 7.25, 7.27, 7.29, 7.31. 7.33, 7.35. 7.37, 7.39,7.41, 7.43, 7.45, 7.47. 7.49. 7.51. 7.53, 7.55, 7.57, 7.59
Route No. 2	8	6.13, 6.28, 6.43, 6.58, 7.13, 7.28, 7.43, 7.58
Route No 3	9	6.13, 6.25, 6.37, 6.49, 7.01, 7.13, 7.25, 7.37.7.49
Route No 4	8	6.13, 6.28, 6.43, 6.58, 7.13, 7.28, 7.43, 7.58
Route No 5	8	6.13, 6.28, 6.43, 6.58, 7.13, 7.28, 7.43, 7.58
Route No 6	12	6.10, 6.20, 6.30, 6.40, 6.50. 7.00, 7.10, 7.20, 7.30, 7.40, 7.50, 8.00
Route No. 7	6	6.13. 6.33. 6.53, 7.13, 7.33. 7.53
Route No 8	23	6.10, 6.15, 6.20, 6.25, 6.30. 6.35, 6.40, 6.45. 6.50. 6.55. 7.00,7.05, 7.10.7.15, 7.20, 7.25. 7.30. 7.35. 7.40,7.45, 7.50.7.55, 8.00
Route No 9	9	6.13. 6.25. 6.37, 6.49, 7.01. 7.13,7.25, 7.37.7.49
Route No 10	8	6.13. 6.28.6.43, 6.58, 7.13. 7.28, 7.43, 7.58
Route No. 11	2	6.41. 7.41

Table 3. Load Factors on feeder buses, Andheri (E), 6a.m. to 8a.m

Route no.	Route loading	Actual no. of buses on Route	Load factors of buses
1	3218	39	0.46,1.11, 1.11,1.11, 1.11, 1.11, 1.11, 1.11 1.11, 1.11, 1.11, 0.50, 1.11, 0.68, 1.11, 1.11 0.90,1.11,1.11, 1.14, 1.11, 1.11, 1.11, 1.11, 0.75, 1.11, 1.11, 1.11, 1.11, 1.11, 1.11, 1.11, 1.11 1.11, 1.11, 1.11, 1.11, 1.03, 0.46, 1.11, 1.11, 1.11 1.11, 1.11, 1.11,1.11 1.11, 0.55, 1.11, 1.11, 1.11 1.11, 1.11,1.11,
2	455	5	0.53,0.77, 0.96, 0.88, 1.11, 1.11, 1.11, 1.11
3	508	6	0.62, 0.83, 0.70, 0.83, 0.98, 1.11, 1.11, 0.83, 1.11
4	405	4	0.50, 0.72, 0.88,0.83, 1.11, 0.94, 1.05, 1.00
5	479	4	0.53, 0.77, 0.96,0.88, 1.11, 1.11, 1.11, 1.11
6	637	5	0.44, 0.96, 0.79, 1.05, 0.62, 1.11, 1.09, 1.11, 1.11, 1.03, 1.05, 0.88
7	340	3	0.37, 0.74, 0.90, 1.11, 0.88, 1.07
8	1377	10	0.94, 0.75, 1.11, 1.11, 0.81, 1.11, 1.11, 1.00, 0.37 1.11, 1.11, 1.11, 1.11, 1.11, 1.11, 1.11, 1.11, 1.11 1.11, 1.11, 1.11, 1.11, 1.11
9	523	6	0.62, 0.83, 0.70,0.83, 0.98, 1.11, 1.11, 0.83, 1.11
10	452	3	0.53, 0.77, 0.96, 0.88, 1.11, 1.11, 1.11, 1.11
11	77	1	0.37, 0.68

which leads to provision of only two buses with load factors less than 1. Here it is not feasible to provide coordinating buses with in acceptable transfer time. It is found that overall average load factors for all the routes is more than 0.8 except route number 11 on Andheri (E) where number of detraining commuters are extremely less. Similar results are obtained for other time periods and for different areas (Shrivastava, 2001). Average load factor for Andheri (E) is 0.85 and for Andheri (W) is 0.98. Whereas overall average load factor for Andheri (E) and Andheri (W) is = 0 .91 which is very close to breakeven value 1.12. The value of load factor will further improve with the en-route demand. Also the value of load factor is better than the present value, which is about 0.81 for a bus capacity of 54. For Vileparle load factors are found to be considerably low because of relatively lesser number of potential alighting passengers who opt for BEST buses from railway station. It is found that more buses are required during morning peak and evening peak periods. In different five periods 161, *322*, 98, *325* and 210 number of buses are required for both Andheri and Vileparle, which is much less than the present requirement for the same demand satisfaction.

Conclusions

The results have proved that simultaneous routing and scheduling using Genetic Algorithm for optimization has better edge over other existing approaches for routing and scheduling problems.

GA has emerged as an efficient technique for multi-objective, non-linear scheduling and schedule co-ordination problems. Time taken to obtain results is directly proportional to adopted pool size. Near optimal results can be obtained even with lesser pool sizes, which may be practically acceptable in the real life situation. GA can obtain depending on the availability of time for computation reasonable practically acceptable results easily. However if computational time is no constraint GA guarantees better results. It is also found that GA is very sensitive to penalties. Wide variation in results is seen due to slight change in any penalty. Therefore appropriate realistic penalties should be decided as per their relative importance for better and acceptable results.

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APPENDIX - I

Brief discussion on Genetic Algorithm

Genetic Algorithms (GAs) proposed by Holland (1975) are based on exhaustive and random search techniques, found to be robust for optimizing non-linear and non-convex functions. In the application of Genetic Algorithm the decision variables are usually mapped and represented by a string (Chromosome) of binary alphabets (genes). The size of the string depends on the precision of the desired solution. For problems with more than one decision variable, a sub-string usually represents each variable. All sub-strings are then concatenated together to form a bigger string. Once the coding of variables has been done, the corresponding point can be found using a fixed mapping rule, (Goldberg, 1989). The operation of GAs begins with population of random strings representing design of decision variables. Thereafter, each string is evaluated to find the fitness value. The population is then operated by three main operators: reproduction, crossover and mutation to create a new population of points. *Reproduction/Selection* operator is usually the first operator applied on a population. Reproduction selects a good string in a population and forms a mating pool. In the *crossover* operator, exchanging information among strings of the mating pool creates new strings. *Mutation* operator is also used sparingly. The need for mutation is to create a point in the neighborhood of the current point, thereby achieving a local search around the current solution. The new population is further evaluated and tested for termination. If the termination criterion is not met, the population is iteratively operated by above three operators and evaluated. This procedure is continued until the termination criterion is met. One cycle of these operations and subsequent evaluation procedure is known as a *generation.* For constraint optimization problems it is appropriate to use penalty method (Deb, 1995).