

## Transit network design and scheduling using genetic algorithm – a review

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**Abstract.** The aim of this paper is to summarize the findings of research concerning the application of genetic algorithm in transit network design and scheduling. Due to the involvement of several parameters the design and scheduling of transit network by means of traditional optimization technique is very difficult. To overcome these problems, most of the researchers have applied genetic algorithm for designing and scheduling of transit network. After the review of various studies involved in design and scheduling of transit network using genetic algorithm, it was concluded that genetic algorithm is an efficient optimization technique.

**Keywords:** Transit network, genetic algorithm, optimization technique

**AMS Classification:** 90B10, 90B15.

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### 1. Introduction

In developing countries like India traffic congestion, slow speed of vehicle and poor level of service are the major problems encountered in our daily life. These problems are due to huge growth of vehicular population specially the private and intermediate transport service [1-3]. In this view of rapid development it necessary to plan and design the public transport system in an efficient manner so that the use of private and intermediate transport service is reduced.

The transport system is efficient if design and schedule of transit network is efficient. From the user point of view, the system is efficient if it meets the demand by providing cheap and direct service to the passenger, and from the operator point of view the system is efficient if it makes as much profit as possible. This is the main challenge in the transit planning to find balance between these conflicting objectives, various optimization techniques come in to the game [4]. Among various optimization techniques the

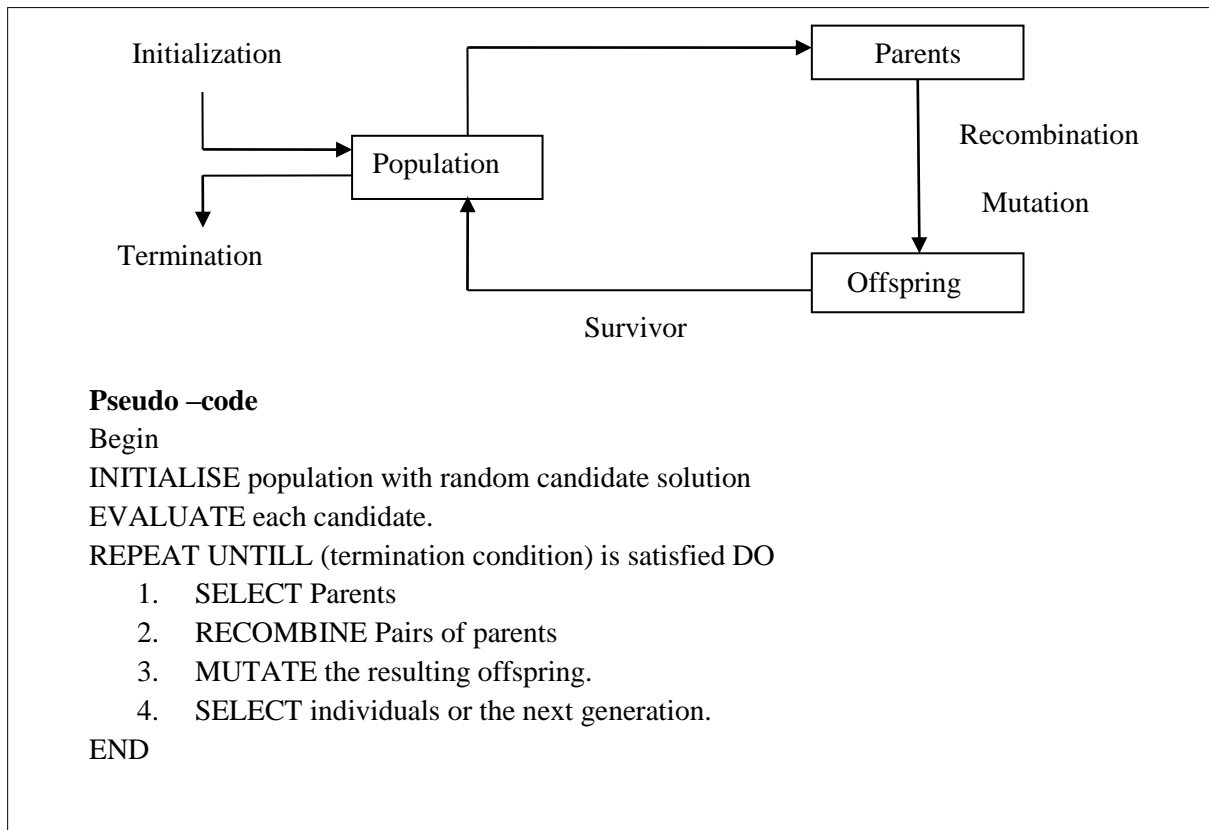
genetic algorithm offers a new strategy with enormous potential for many tasks in planning and designing of transit network. It is an area of interest indicating how genetic algorithm addresses the shortcoming of conventional optimization techniques. In the present study an attempt has been made to explore the application of genetic algorithm in routing, scheduling, combined routing and scheduling and integration of mass transit planning.

### 2. Genetic algorithm

Genetic algorithms, search optimization techniques are based on the mechanics of natural selection. It is an evolutionary algorithm. The basic mechanics of genetic algorithm are simple involving copying strings and swapping partial strings. The major steps involve in the GA implementation algorithm are generation of population, finding the fitness function, and application of genetic operator and evaluation of population [5] as shown in Figure 1.

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**Figure 1.** General scheme of evolutionary process [6]

GA starts with the population of randomly created string structure representing the decision variable. The size of the population depends upon the string length and problem being optimized. These strings are called chromosome in biological system. The associate value with the chromosome is called the “fitness function”. These strings consist of coding and binary coding which is most common coding method and GA performs best if adopted [7] i.e. ones and zeros or “bits”. Every position in chromosome consists of “genes” having value as “allele” (e.g., 0 or 1). Initially the allele of chromosome is generated as simple tossing of an unbiased coin and consecutive flips (head=1 and tail=0) can be used to decide genes in coding of a population strings. Thus population having individuals is generated by pseudorandom generator whose individuals represent a feasible solution in solution space called initial solution. After deciding the encoding method as binary strings, its length is determined according to desired precision. While in the process of coding, the corresponding point can be found using fixed mapping rule [7]. Suppose the function of  $n$  variables,  $f(x_1, x_2, \dots, x_n): \mathbb{R}^n \in \mathbb{R}$  to be minimized for each decision variable  $s_i$  then linear mapping rule is:

$$X_i = X_{i\min} + \frac{X_{i\max} - X_{i\min}}{2^{m_i} - 1} \times \text{decoded\_value} (S_i) \quad (1)$$

Where,

$X_{i\min}$  = lower bound on decision variable  $X_i$

$X_{i\max}$  = upper bound on decision variable  $X_i$

The variable  $X_i$  is coded into substring  $S_i$  of length  $m_i$  then,

Decoded value ( $s_i$ ) is  $\sum_{i=0}^{i=1} 2^i S_i$ , where  $S_i \in (0, 1)$

and string is represented as  $(S_{m-1}, S_{m-2}, S_2, S_1, S_0)$ . After decoding all decision variables using above mapping rule, the function value can be calculated by substituting the variables in the given objective function  $F(x)$ . The objective function value is used as a measure of “goodness” of the string and called as “fitness” in GA terminology. The obtained accuracy of a variable for a  $m_i$ -bit coding is

$$\frac{X_{i\max} - X_{i\min}}{2^{m_i} - 1} \quad (2)$$

In the next step, fitness function  $f(x)$  is derived from the objective function and used in

successive genetic operators. GAs is naturally suitable for solving maximization problems while for minimization problems are transformed into maximization problems using suitable transformation. For maximization problems, fitness function is the same as objective function i.e.  $f(x) = F(x)$ . For minimization problems, the fitness function is an equivalent maximization problem chosen such that the optimum point remains unchanged. The fitness function used is [8]:

$$F(x) = \frac{1}{[1 + f(x)]} \quad (3)$$

With fitness function value of each string in particular generator, maximum, minimum and average fitness values of all strings in a population are calculated and checked for termination criteria. If the termination criterion is not satisfied then new population is created by applying three main genetic operators – reproduction, crossover and mutation.

**Reproduction / Selection:** [7, 9] is a process in which individual is copied considering their fitness function values to make more copies of better string in a population. This represents a measure of the utility or goodness related to what we want to maximize. Copying strings according to their fitness function values means that string with a high value have higher probability of contribution to one or more off-spring in the next generation. In all selection schemes the essential idea is to pick strings with more than average fitness value from current population and their multiple copies are inserted in the mating pool in a probabilistic manner as shown in Figure 2. The most commonly selection operator are uniform random selection, roulette selection and tournament selection. The former selects member of pool at random, ignoring fitness or other factors. Thus the chromosome is likely to be selected. The simplest way to implement the reproduction operator is to create a biased roulette wheel where each string in the current population has a slot sized proportionally to its fitness function value. The formula used to calculate the slot size of roulette wheel, corresponding to the reproduction probability  $p_r(i)$  of the string is as follows:

$$\text{Reproduction probability } P_r(i) = f_i / \sum_{i=1}^n f_i \quad (4)$$

Where,  $n$  = Population size

$f_i$  = fitness value of  $i$  string.

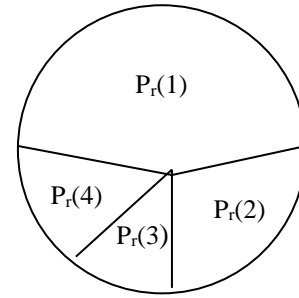
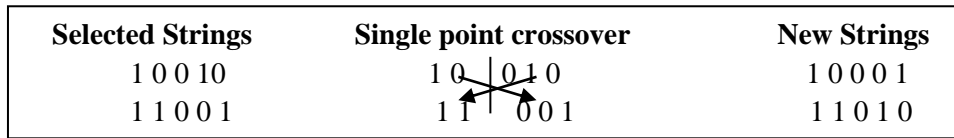


Figure 2. Reproduction operator

**Crossover:** [7, 9] after reproduction, crossover is applied to the string of mating pool. A crossover is used to combine two strings with the hope of creating better string. It can performed with the probability ( $P_c$ ) to restrict some of the good string found previously. Two strings are chosen at random for crossover. The most commonly used crossover operators are single point crossover, double point crossover. A crossing site (represented by vertical line) is chosen at random. The contents in the right side of the crossing side are swapped between the strings. The essential idea of crossover is to exchange bits between two good strings to obtain a string that is generally better than the parent. For example, a single point crossover on five bit string is shown in Figure 3.

**Mutation:** [7, 9] adds new information in a random way to genetic search process and prevents an irrecoverable loss of potentially useful information which reproduction and crossover can cause. It operates at bit level, when bits are copied from current string to new string. Mutation operates with a very small mutation probability ( $p_m$ ). It introduces the diversity in the population whenever the population trends to become homogeneous due to iterative use of reproduction and crossover. A coin toss mechanism is used; if a random number between 0 and 1 is less than the mutation probability, then bit is inverted i.e. 0 become 1 and 1 become 0. There are different type of mutation operator flip-bit, boundary, uniform, non-uniform and Gaussian. Flip-bit operator is used for binary gene; boundary, uniform, non-uniform and Gaussian operator is used for integer and float gene. In this paper the example using binary gene has been considered. To understand how to use integer gene refer [10].



**Figure 3.** Crossover operator

The newly created strings are evaluated by decoding and calculating their objective function values (fitness). This whole process completes one cycle of GAs, normally called as generation. Such iterative process continues until the termination criterion is satisfied.

**Termination Criteria:** the population is said to be converged, when the average fitness of all the string in a population is equal to best fitness. When the population is converged, the GAs is terminated.

### 3. Review of GAs in design and scheduling of transit network

Various attempts have been made in designing and scheduling of transit network by different researchers. The design and scheduling of transit network using GAs has been classified into four broad categories: Routing, scheduling, combined routing and scheduling and integration of mass transit planning. Table 1 provide an overview of the approaches reported in the literature.

#### 3.1 Routing approaches

Design of a route is an important step in planning the transit system. Bus/rail takes a major share of public transport demand. However, in most of the service areas the distribution of passenger travel is not homogenous; and therefore such location may not be cost effective in terms of operator or user point of view. For better passenger accessibility and saving of cost, reconstruction of bus route and its associated frequency must be done to suit the travel demand results in better passenger accessibility and saving of operating cost. Transit operator and commuter both give preference to short routes so that the operator cost and the travel time can be decreased, respectively.

Generally, the passengers also prefer those routes that can be easily accessed from their origin or destination trip. The route set is efficient if it satisfies the following rules:

- i. The transit demand of all commuters.
- ii. Transit demand of all commuters with zero transfer.
- iii. Less time to travel.

Pattnaik *et al.* [11] focused on route network design and calculated associated frequencies for a given set of routes using genetic algorithm (GAs). Design consisted of two phase; first of all candidate route set was generated and then using GAs optimum route set was selected. The GAs was solved by fixed string length coding scheme assuming a solution set route size, and tried to find many best routes from the candidate route set. Newly proposed variable string length method was used to found the solution route set size and set of solution routes.

Bielli *et al.* [17] focused on a new method of computing fitness function (ff) values in genetic algorithm for bus optimization. Each set was evaluated by computing a number of performance indicators obtained by analysis and aimed to achieve best bus network satisfying both demand and offer of transport. The algorithm was used to generate iteratively new set of bus networks.

Ngamchai and Lovell [23] proposed a new model to optimize bus route design which incorporates unique frequency setting for each route using GAs. The model design the bus route in three phases; firstly an initial set of route is constructed which are feasible and good. Secondly the service frequency on each route was assigned and headway coordination techniques were applied by ranking of transfer demand at transfer terminal. Lastly the existing route was modified to identify the shortest paths between origin and destination. The efficiency of the model was tested by applying it on the benchmark network. The performance result shows that proposed model is better than binary-coded genetic algorithm.

Chien *et al.* [21] develop a model using GAs to optimize bus transit system. The total cost function consisting of supplier and user costs was minimized subject to realistic demand distribution and irregular street pattern. The quality and quantity of the data can be improved by incorporating boarding demand data of census block and information of GIS (Geographical Information Systems) street network.

**Table 1.** Classification of papers dealing with design and scheduling of transit network

<b>Year</b>	<b>Author</b>	<b>Objectives</b>	<b>Decision variables</b>	<b>Network structure</b>
1998	Pattnaik <i>et al.</i> [11]	Total cost (user + operator )	Route, frequencies	Irregular grid
1998	Deb & Chakroborty [12]	Passenger waiting time	Arrival time, departure time	Not specified
2000	Gundaliya <i>et al.</i> [13]	Total cost (user + operator )	Route, frequencies	Irregular grid
2001	Chien <i>et al.</i> [14]	Total cost (user + operator )	Route, headway	Rectangular grid
2001	Kalaga <i>et al.</i> [15]	Crowding level	Route, frequencies	Irregular grid
2001	Chakroborty <i>et al.</i> [16]	Total waiting time (passenger)	Arrival time, departure time	Not specified
2002	Bielli <i>et al.</i> [17]	Multi-objective	Route, frequencies	Irregular grid
2002/ 2006	Shrivastava & Dhingra [18,19]	Total cost (user + operator)	Route, frequencies	Not specified
2002	Chakroborty & Diwedi [20]	Multi-objective	Route	Irregular grid
2003	Chien <i>et al.</i> [21]	Total cost (user + operator)	Route spacing, headway, stop spacing	Rectangular grid
2003	Tom and Mohan [22]	Total cost (user + operator)	Route, frequencies	Irregular grid
2003	Ngamchai & Lovell [23]	Total cost (user + operator)	Route, frequencies	Irregular grid
2004	Agrawal & Mathew[24]	Total cost (user + operator)	Route, frequencies	Not Specified
2005	Kidwai <i>et al.</i> [25]	Passenger wait time and crowding level	Route, frequencies	Irregular grid
2006	Zhao & Zeng [26]	Coverage, transfer, user cost	Route, frequencies	Irregular grid
2006	Kaun <i>et al.</i> [27]	Total cost (user + operator)	Route	Not Specified
2006	Verma & Dhingra [28]	Total cost (user + operator)	Route, headway	Irregular grid
2006/ 2007	Shrivastava & O'Mahony [29,30]	Total cost (user + operator)	Route, frequencies	Irregular grid
2010	Wang and Lin [31]	Operator cost, passenger travelling cost	Route, frequencies, capacity, headway	Not specified
2012	Chew and Lee [32]	Passenger Cost	Route	Irregular grid

The developed model determines the optimal solution and generates relationship among variables. The service area was divided into

various sub-regions to deal with multiple bus routes situation. Agrawal and Mathew [24] proposed two parallel computational models for

urban transit network using parallel genetic algorithm (PGA). The first model i.e., global parallel virtual machine (PVM) calculates the fitness function. The second model i.e., global message passing interface (MPI) substitutes MPI environment for PVM libraries. The large transit network consisting of 1332 nodes, 4076 links and 6000 demand pairs was used as a case study. Both the models were tested for better performance using various factors, like efficiency, computation time and speedup. Based on the performance measure, it is identified that global PVM model is efficient than the other model.

Wang and Lin [31] developed a bi-level programming model using genetic algorithm for mass transit route network design (MTRND). The TRTC (Taipei Rapid Transit Corporation) mass transit network was used as a case study. To attain better search space for initial feasible solution, the algorithm was formulated with smart generating methodology. The computation time of an efficient network model can be minimized using redundancy checking mechanism and gene repairing strategy. The solution quality is improved by embedding the passenger assignment model and improved fitness function. Based on the comparison between performance measures, such as two initial solution generating methods (1-car and Minimum-car) and three operators (1-point, 1-point mutation and 2-point crossover), it was found that for MTRND problem proper combination of minimum-car method and the 2-point crossover operator was suitable. The result identifies that development model and algorithm is effective for solving MTRND problem.

Chew and Lee [32] developed a framework using GAs to solve urban transit routing problem (UTRP). In this study, the infeasible solution was converted into feasible solution using adding-node procedure. Minimizing the passenger cost was the main objective of the study. To perform genetic operation, route crossover and identical-point mutation were proposed. The Mandl's benchmark data set was used to carry out the computational experiment. The result shows that the proposed algorithm performs more efficiently when compared to other researchers as shown in Table 2.

### 3.2 Scheduling approaches

Careful and detail scheduling computation and precise presentation of schedulers are extremely important aspects of transit system operation. They affect efficiency and economy of operation,

regularity and reliability of service and facility with which public can use system. Good scheduling means spacing transit vehicle at appropriate intervals throughout the day and evening to maintain an adequate level of service. Therefore, it minimizes both waiting time for passengers as well as transfer time from one route to another. Total waiting time of passengers is the sum of the total initial waiting time (IWT) and total transfer time (TT) of the passenger. As an effect, it will provide a better level of service to passenger at no extra cost. The resource and service related constraints are as follows:

- i. Minimum fleet size: number of buses available should be finite for running on different routes.
- ii. Minimum Bus capacity: capacity of the bus should be fixed.
- iii. Stopping time bounds: buses cannot stop for a very little or a very long time at a stop.
- iv. Policy headway: minimum frequency level should be maintained on a given route.
- v. Maximum transfer time: transfer time for the passenger should not be too long.

Deb and Chakroborty [12] formulated the time scheduling problem of transit system into mixed-integer nonlinear programming problem (MINLP) while considering large number of resources and service related constraint like size of fleet, stopping time and headway. Minimize the total waiting time (initial waiting time + transfer time) of the passenger is the main objective of MINLP. Genetic algorithm based approach was selected to solve transit scheduling problem as difficulties rises while using conventional optimization techniques. This research shows that the GAs based approach with least modification can handle various transit scheduling problems, such as minimum versus maximum capacity of bus, static versus dynamic arrival time, and single versus multiple transfer stations. Result shows that GAs based approach is capable of finding optimal results.

Kalaga *et al.* [15] presented a two-step based heuristic technique for the distribution of buses on urban bus route. In the first step, bus frequencies required to manage the peak demand on each route was worked out. To compute base frequencies, buses overcrowding at certain location was also included.

**Table 2.** Comparison of GAs model with models developed by other researchers [18]

Authors	Case	Number of routes	Parameters				
			% of Demand satisfy through transfer				
			Zero	One	Two	Unsat	ATT
Mandll [33]			69.94	29.93	0.13	0.00	12.90
Baaj and Mahmassani [34]			N/A	N/A	N/A	N/A	N/A
Kidwai [25]			72.95	26.92	0.13	0.00	12.72
Chakroborty and Dwivedi [20]	I	4	86.86	12.00	1.14	0.00	11.90
Fan and Mumford [35]			93.26	6.74	0.00	0.00	11.37
Proposed GAs			92.88	6.91	0.20	0.00	11.16
			93.71	6.29	0.00	0.00	10.82
Mandll [33]			N/A	N/A	N/A	N/A	N/A
Baaj and Mahmassani [34]			78.61	21.39	0.00	0.00	11.86
Kidwai [25]			77.92	19.68	2.40	0.00	11.87
Chakroborty and Dwivedi [20]	II	6	86.04	13.96	0.00	0.00	10.30
Fan and Mumford [35]			91.52	8.48	0.00	0.00	10.48
Proposed GAs			93.85	5.88	0.24	0.03	10.51
			95.57	4.43	0.00	0.00	10.28
Mandll [33]			N/A	N/A	N/A	N/A	N/A
Baaj and Mahmassani [34]			80.99	19.01	0.00	0.001	12.50
Kidwai [25]			93.91	6.09	0.00	0.00	10.69
Chakroborty and Dwivedi [20]	III	7	89.15	10.85	0.00	0.00	10.15
Fan and Mumford [35]			93.32	6.36	0.32	0.00	10.42
Proposed GAs			96.47	3.53	0.00	0.00	10.31
			95.57	4.43	0.00	0.00	10.27
Mandll [33]			N/A	N/A	N/A	N/A	N/A
Baaj and Mahmassani [34]			79.96	20.04	0.00	0.00	11.86
Kidwai [25]			84.73	15.27	0.00	0.00	11.22
Chakroborty and Dwivedi [20]	IV	8	90.38	9.62	0.00	0.00	10.46
Fan and Mumford [35]			94.54	5.46	0.00	0.00	10.36
Proposed GAs			96.16	3.84	0.00	0.00	10.31
			97.82	2.18	0.00	0.00	10.19

Avg: Average, Unsat: Unsatisfied, ATT: Average Travel Time

In the second step, additional frequencies were allocated in order to minimize the level of overcrowding in the network. The problem of commuters' discomfort because of overcrowding was formulated as non-linear objective function.

The problem, such as allocation of superfluous was solved using GAs. Route overlapping has been considered and a frequency of buses according to one transfer was set. The model concentrates on overcrowding as measure of user cost; other factors, like waiting time and vehicle

operating cost are not taken into account, which play a major role in allocation of buses. At intermediate node maximum of one transfer was considered that is generally not an actual case.

They generated frequency-setting (FRESET) model and minimized the objective function subject to constraints of feasibility loading, assignment of commuter flow and size of fleet. Loading feasibility constraint ensured that the passengers demand across each route was fulfilled by allocation of frequency of buses across each route. Two stages of FRESET model were: Base frequency allocation and surplus allocation.

Chakroborty *et al.* [16] presented a genetic algorithm based approach for optimizing the problem related to allocation of fleet size and development of schedule with transfer consideration as well as minimizing the passenger waiting time. From the past experiences, it has been identified that it is impossible to get optimal result for simple problem using conventional optimization method but it is possible to get optimal result with minimum computation effort using GAs. Limitation of the developed method is that string length in case of a larger network is generally large. Two points that needs attention are; (i) developed a real- coded GAs based approach (ii) proposed procedure must be included with transfer stops.

Shrivastava and Dhingra [18] developed a Schedule Optimization Model (SOM) for coordinating schedule of BEST buses determined on existing feeder routes. Minimizing transfer time between buses and train and operator cost are the main aims of the proposed model. The problem becomes nonlinear and non-convex due to large number of variables and constraint in the objective function, making it difficult to solve due to traditional approaches. Therefore, for coordination of sub-urban train and buses a genetic algorithm was used which is a robust optimization technique. The proposed model provides a better level of service to the commuters because they consider load factor and transfer time from train to bus rather than fleet size. It was found that less number of buses is required on existing feeder routes and it is a specific contribution towards integration of public transport mode.

Kidwai *et al.* [25] presented a bi-level optimization model for bus scheduling problem. (iv) proportion of demand unsatisfied (4) average travel time per user in minutes (5) total man-

In first level, load feasibility was determined for each route individually and by adding the number of buses across each route, the fleet size was determined. In second level, using GAs the fleet size obtained from the first level is again minimized. Model is applied to real life network and based on the result, it is concluded that proposed algorithm yields significant saving for transit network with overlapping of routes.

### 3.3 Routing and scheduling approaches

Problems related to vehicle routing and scheduling (VRS) involve four decisions; (a) vehicle fleet size, (b) customer are assigned to a vehicle, (c) assigning a sequence to the vehicle which travel to the assigned customer, and (d) completing its route the actual time that vehicle travel. To solve the problem, various techniques have been used but no technique has included all the practical options or restriction confronting to a company. Unfortunately, the analysts had to be satisfied with the existing method or with slight modification they can develop their custom solution techniques. Routing and scheduling also mean an approach which deals with the route configuration and respective frequency simultaneously. This combined process of routing and scheduling involves two decisions parameters: number of routes and associated frequency.

Gundaliya *et al.* [13] proposed a GAs to develop a model for routing and scheduling. Objective function is minimization of total cost that is user and operator costs and the related constraints are load factor, fleet size and overloading of links. User cost is a combination of in-vehicle time, waiting time and transfer time and operator cost is vehicle operating cost of buses. Mandl's Swiss network of fifteen nodes was used to test the model. Model gives the better optimized results found by other researcher on same network and demand matrix.

Chakroborty and Dwivedi [20] proposed an algorithm using GAs that provides an efficient transit route networks. In this paper, four cases with different number of routes in the route set were used. A comparison of the proposed algorithm with algorithm developed by other author is done using various measures of effectiveness, such as (i) percentage of demand satisfied directly (ii) proportion of demand satisfied with one transfer (iii) proportion of demand satisfied with two transfers hours saved per day. They also state that the developed procedure uses non-heuristic



techniques in optimization process. Further they mentioned that the proposed procedure is useful for transit planners and designers.

Tom and Mohan [22] designed a route network for transit system involving selection of route set and its related frequency. The problem was formulated as an optimization function that minimized the overall cost of the system (operating cost of bus + travel time of passenger). Design of the route network was done in two stages: In the first stage, a large set of candidate route set was generated. In the second step, a solution route set with associated frequencies was chosen using GAs, from the large set of candidate route set generated during first step. The proposed model considered route frequency as the variable, thus making it different from the existing model in terms of adopted coding method. The model was studied on small size network and found that the performance of the model can be evaluated using adopted coding method for design of transit network. The SRFC model provides a solution with minimum operational cost, minimum fleet size and maximum allocation of demand which is directly satisfied. Using asymmetric demand matrix and demand sensitiveness to the service quality, this study can be extended.

Chakroborty [36] discussed the optimal routing and optimal scheduling problems and described that the problem of routing can be classified as vehicle routing (TSP (travelling salesman problem), SVPDP (single vehicle pick-up and delivery problem) and SVPDPTW (single vehicle pick-up and delivery problem with time windows) and the transit routing problem. To develop schedules for bus arrival and departure at all the stops of network for a given set of route was the optimal scheduling problem. The genetic algorithm was used to solve optimization problem which was difficult to solve using conventional optimization tools. Results for various routing and scheduling problem were obtained by applying GAs technique.

Zhao and Zeng [26] demonstrated a mathematical based stochastic methodology for optimizing transit route network using integrated Simulated Annealing (SA) and GAs search method. A computer program was developed to implement the methodology, and previously available results were used to test the feasibility of the proposed methodology. By developing time-dependent transit network optimization methods, the present study can be enhanced further to optimize a transit network for both periods that is peak and

off-peak which also takes into account the waiting time and transfer penalties. It is also necessary to analyze the objective functions defined in terms of commuters and operator costs. To correctly identify the difference between two lines (i.e., is bus and rapid transit line), it is necessary to use the travel time instead of travel distance.

### 3.4 Integration of mass transit planning

Integration of mass transit planning means development of feeder routes and schedule coordination simultaneously. In integrated system, all the trips involve more than one mode and since passengers are subjected to transfer. The transfer is one of negative aspect of any trip but cannot be neglected. Transfer is essential because it make the integrated system quick and convenient.

Dhingra and Shrivastava [37] described the methodology for co-ordination of suburban railway and BEST buses at Mumbai. The aim of this study was to achieve optimal coordinated schedules for optimally designed feeder route network with due consideration to user and operator costs and better level of service. To meet these objectives, network optimisation and transfer optimisation models were proposed. The problem was of multi-objective nature therefore a strong optimization technique GAs was proposed for optimisation. The objective function contains minimisation of in-vehicle travel time, standing passengers and vehicle operating cost.

Kaun *et al.* [27] presented a methodology for solving the problem related to feeder bus network design using meta-heuristic (combination of GAs and Ant Colony Optimization (ACO)). To compare the performance of meta-heuristic in terms solution quality and computational efficiency, a comparison was done between randomly generated 20 test solutions. In this study, each route was sequentially developed as follows: firstly the station was randomly selected, secondly the selected stop was added to the route linking to selected station, and lastly the route length was checked. The current route is terminated if it exceeds the maximum route length, and a similar procedure is used to develop new route. The procedure continues until all the stops have been included in the routes. To test the base problem, the results are compared with those published in the literature. Computational experiments have shown that both heuristics (simulated annealing and tab search) are comparable to the state-of-the-art algorithms.

Results also indicate that procedure can be further improved by using a 3-opt procedure (used to optimize each route) formed by applying GAs and ACO, so that the performance could be as good as that of tabu search with intensification.

Shrivastava and O'Mahony [29, 30] build a model using GAs for generating the optimized feeder routes and indentifying associated frequencies for coordinating schedule of feeder buses. Thus instead of decomposing the problem in two steps (i) feeder route development (ii) schedule coordination of feeder buses, the two steps were optimized together that were complementary to each other. In this study, the authors determined the schedules coordination of feeder buses for the existing given schedules of main transit. The model produced better results in terms of improved load factor as compared to previous technique accepted by author for the same study area. The proposed model involves real life objective and constraints therefore it is specific involvement towards realistic modeling of integrated public transport system.

Shrivastava and Dhingra [19] developed a methodology that determines the feeder routes and coordinated schedules for coordinating feeder buses with suburban trains. Feeder routes were developed using heuristic feeder route generation algorithm, and GAs was used for optimizing coordinated schedules. Based on the load factor and bus waiting time, the schedules were decided. To maintain better level of service and waiting time within satisfactory limit, the load factor lies between minimum and a maximum values. From the results, it is found that optimal values can be obtained in lesser time using genetic algorithm.

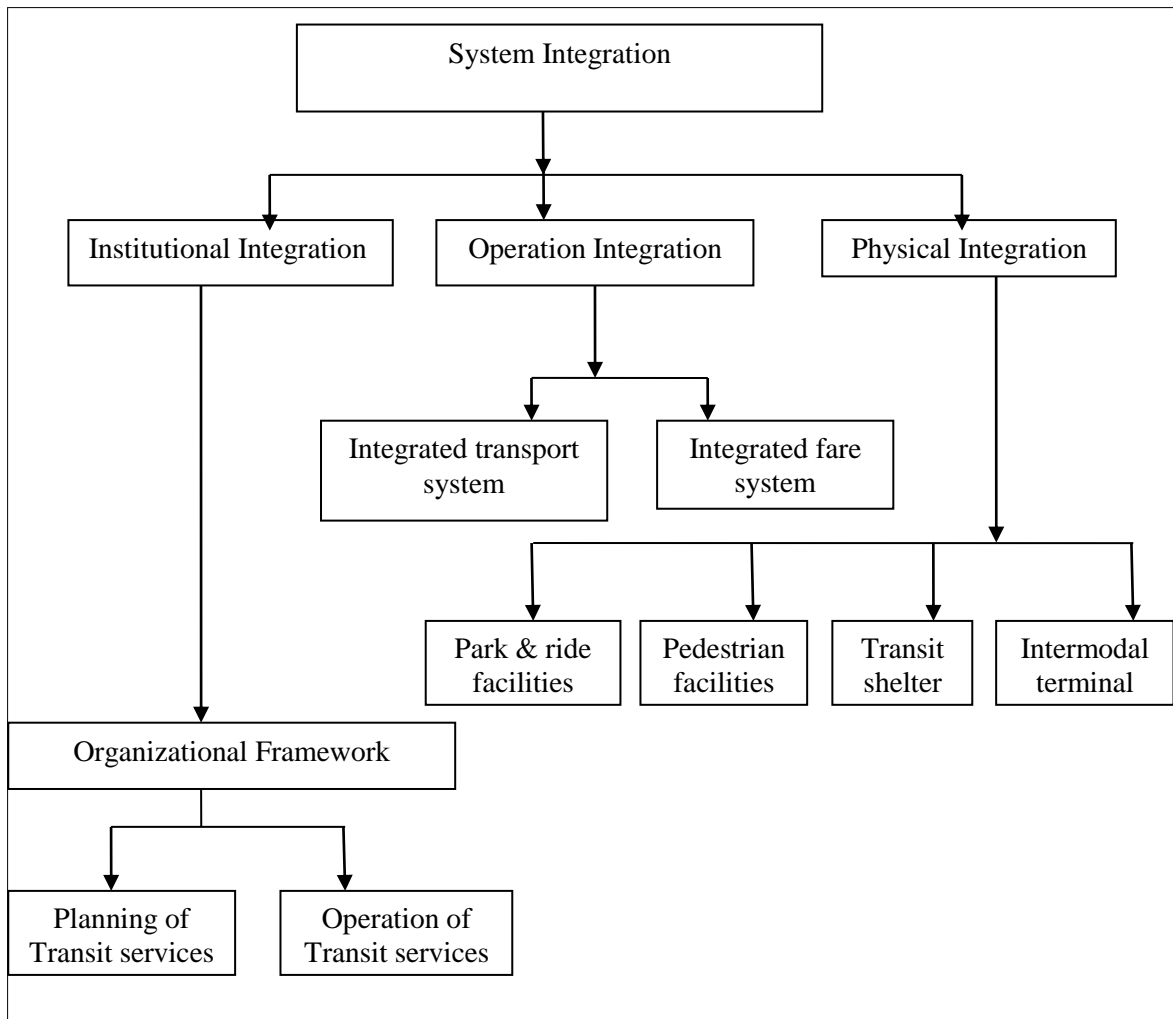
Verma and Dhingra [28] described a model for building optimal coordinated schedules for urban rail and feeder bus operation. An optimization technique GAs was used for developing a model. In this study, the optimal coordinated of urban train and feeder buses was done in two parts; (i) sub-model was developed for train scheduling, and (ii) sub-model was developed for schedule coordination. The train scheduling objective function is taken as minimization of train operating cost and passenger waiting time cost (boarding the train) subject to constraint load factor and waiting time. The schedule

coordination objective function is taken as minimization of sum of bus operating cost, passenger transfer time cost (transferring from train to feeder buses), and passenger waiting time cost (boarding along the feeder route) subject to constraint load factor and transfer time. Two cases were considered for coordination, in first case, buses of different types were considered, and in second case single-decker fleet buses were considered. A comparison between both the cases was done to choose the strategy that is best. On the basis of comparison, it was found that mixed fleet size buses produce optimum result for coordinated feeder bus schedules.

After examining and interpreting various literatures it is concluded that studies up until recent times are limited to operational integration of mass transit planning. The efficiency of different mass transit modes and main transit facility can be enhanced by overall system integration. The overall system integration includes operational integration, institutional integration and physical integration as shown in Figure 4.

#### 4. Conclusion

In this review paper, we have presented the classification and analysis of studies on design and scheduling of transit network using GAs. It was found that problem related to design and scheduling of transit network are highly complex and non-linear in terms of decision variable and difficult to achieve using classical programming. GAs an optimization technique is computationally more efficient to solve the problem requiring large number of resources and services related constraints such as design and scheduling of transit network. Based on the review, it is concluded that GAs have advantage over traditional optimization techniques, as they work with clusters of points rather than a single point. Due to simultaneous process of more than one string it increases the possibility of global optimum solution. But still there exists some limitations: the solution for the complex problems is efficient if the evaluation of the fitness function is good. But to evaluate a good fitness function is mostly the hardest part.



**Figure 4.** Overview of system integration

## 5. Future scope

For future scope the following points are recommended:

1. The efficiency of the integrated transport system can be enhanced by overall system integration.
2. The developed integrated transport system can be extended by developing integrated fare system between integrated modes which is a part of operation integration.
3. Up till now, the developed integrated systems consider the train as the main mode and the bus and the intermediated transport system (auto-rickshaw and taxi) as feeder modes. In order to develop a fully integrated transport system, personalized modes (car and two-wheeler) and non-motorized modes (cycle-rickshaw & cycle) should also be considered.

## List of Abbreviation

Gas	: Genetic Algorithm
SA	: Simulated Annealing
ACO	: Ant Colony Optimization
ff	: Fitness function
GIS	: Geographical Information System
PGA	: Parallel Genetic Algorithm
PVM	: Parallel Virtual Machine
MPI	: Message Passing Interface
MTRND	: Mass Transit Route Network Design
TRTC	: Taipei Rapid Transit Corporation
UTRP	: Urban Transit Routing Problem
Avg	: Average
Unsat	: Unsatisfied
ATT	: Average Travel Time
IWT	: Initial Waiting Time
TT	: Transfer Time
MINLP	: Mixed Integer-Non-Linear Programming Problem
FRESET	: Frequency-Setting
SOM	: Schedule Optimization Model

VRS : Vehicle Routing and Scheduling  
 TSP : Travelling Salesman Problem  
 SVPDP: single vehicle pick-up and delivery problem  
 SVPDPTW : Single Vehicle Pick-up and Delivery Problem with Time Windows

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