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Metaheuristic approaches for urban transit scheduling problem: A review

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ABSTRACT

Urban Transit Network Design Problem (UTNDP) focuses on deriving useful set of routes, manageable timetabling for each transit route and transit scheduling based on available resources. UTNDP is commonly subdivided into Urban Transit Routing Problem (UTRP) and Urban Transit Scheduling Problem (UTSP), respectively. There are various approaches applied to solve the UTSP. The aim of this paper is to give a comprehensive list of studies on UTSP that deals with metaheuristic approaches such as Tabu Search, Simulated Annealing, Genetic Algorithm and their hybrid methods. This review also addressed possible gaps of the approaches and the limitations of the overall problem. It can be concluded that only some of the metaheuristic approaches and sub-problems are highly studied in UTSP. This review will be useful for researchers who are interested in expanding their knowledge and conduct research in UTSP using metaheuristic approaches.

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1. Introduction

Urban transit network design problem (UTNDP) is a basis for an effective public transit system. It consists of deriving the useful set of routes, manageable transit timetabling for each route and transit scheduling based on available resources. Generally, the quality of public transit system is not constant and always depends on satisfying passengers' and operators' preferences and also requirements of certain areas which is always changing with respect to the development of places and increasing population. In the actual system, planning a competent public transportation system is necessary to intensify its advantages which are traffic congestion, mobility enhancement and reducing environmental pollution. Besides that, creating robust public transit system is needed to maintain sustainability and sensitivity of the system to individual elements and operating conditions under competitive market. The real-world importance of improving public transit system leads to the

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development of theoretical modelling that acts as an alternative methodology to represent and solve the problem quantitatively.

The study on transit planning was first published in 1925, examining a number of empty seats but more advanced methods are used along the years, especially after 1960’s that begins by observing fewer constraints with simple example applications [1]. The success of solving UTNDP is likely connected to type of methods applied and is worthy to be studied in order to reduce the computational time while increasing the solution quality.

There are various reviews in the literature that studied UTNDP concerning different objectives, decision variables, constraints, parameters and the solution methods. These elements are determined based on the complexity of the problems. The first survey on UTNDP is by Chua [2] who studied the planning of urban bus routes and frequencies. Then, Ceder [3] pointed out the needs to connect software system designer and real transit scheduler and presents framework and examples of practical methodologies to overcome urban transit scheduling problem (UTSP). On the other hand, public transit by Desaulnier and Hickman [4] described the transportation problem according to various planning processes which are strategic, tactical, and operational and also real time control by operations research methods. Guihaire and Hao [1] followed the path of Desaulnier and Hickman [4] by summarized majority of the previous studies on strategic and tactical processes according to different solution approaches.

Kepaptsoglou and Karlaftis [5] presented a review based on design objectives, operating environment parameters and solution approaches. A review by Farahani et al. [6] emphasized on the studies related to network topology including road network design problem in both strategic and tactical levels while Johar et al. [7] focused the studies on transit network design and scheduling that solved by Genetic Algorithms (GA). To the best of our knowledge, there is less attention given in the review of the literature that focused on the UTSP.

Based on the literature, solving the UTNDP is a chronological process; the output of the previous step is the input for the preceding steps. It is more complicated to tackle it simultaneously that makes it a NP-hard problem [1]. The objectives and constraints used are based on specific industry rules and preferences. Some of the objectives that taken into consideration according to priority are minimization of operational cost and route length, minimization of waiting time at stations and transfer points, minimization of fleet size, minimization of working hours for drivers, minimization of number of transfer, minimization of overcrowding and minimization of toxic gases emissions. The common constraints adapted from all types of transits are transit capacity, passengers’ demand, transit availability, transit crew preferences, time constraints based on company’s regulations, transit regularity and transfer synchronization.

The main motivation of this review is to show the successful implementation of metaheuristic approaches in UTSP involving buses. The problem is chosen as it covers the majority of the important sections in UTNDP which are frequency determination, timetabling, transit scheduling and crew scheduling to satisfy passenger’s and authority’s preferences. Meanwhile, metaheuristic approaches have gained much interest among researchers to study the UTSP. Thus, it is necessary to produce a critical survey on its application in this area in order to improve the knowledge and perceptions. Besides that, there are many surveys conducted on planning transit route network as compared to scheduling process. This review will extend the past researches to prepare a complete guideline in UTSP. This review will also addressed possible research gaps in this field to extend the understanding to overcome the UTSP.

2. Classification of UTNDP

In order to minimize the complexity of the problem, the UTNDP is classified into several subproblems according to the researcher's expertise. Based on Ceder and Wilson [8], UTNDP is categorized into five stages: transit route network design, transit network frequency setting, transit network timetabling, transit crew scheduling, and rostering. Moreover, the UTNDP can be divided into two main catalogues which are road network design problem (RNDP) and transit network design and scheduling problem (TNDSP) [6]. The RNDP is further reduced to discrete, continuous and mixed network design problems. Meanwhile, the TNDSP is further classified into transit network design problem, transit network design and frequency setting problem, transit network frequency setting problem, transit network timetabling problem and transit network scheduling problem.

In 2003, the UTNDP is further simplified into urban transit routing problem (UTRP) and UTSP by Chakroborty [9]. The UTRP refers the finding of routes for public transit with short travel time and less transfers by considering tolerable cost. Meanwhile, the UTSP concerns with constructing accurate schedule in a predefined set of routes with short waiting time by satisfying demand at each period of time [10]. The UTRP is a strategic process which involves designing proper routes for long-term benefits while the UTSP consists of tactical process which is not constant but changes according to current demands of passengers and operational planning for assigning vehicles with respect to various restrictions. This classification is easy for analysis and implementation. This is because it is precise and understandable. This system of classification helps distinguish the two main problems clearly. This review will use the term from Chakroborty [9] for the remainders of this paper with focus on UTSP.

2.1 Urban Transit Routing Problem (UTRP)

Urban Transit Routing Problem (UTRP) is a process of determining a set of routes linking various locations within a service region based on required design criteria. Route plan design is followed by passenger's movements. The routes are constructed to connect different locations and areas that have high demand for public transit such as activities related to centres and residential areas. Besides that, there are multiple parameters for accurate problem representation such as routes and frequencies that represent as decision variables, network structure, demand characters and patterns that act as operating environment, operational tactics and available resources [5]. These are also useful for assigning as constraints. Generally, a set of routes must satisfy existing transit demand, reduce number of transfer from one route to another and set low travel time to maintain its effectiveness [11].

2.2 Urban Transit Scheduling Problem (UTSP)

Urban Transit Scheduling Problem (UTSP) is defined as a process of developing effective schedule for transit arrivals and departures at demand stops in a given set of routes by using limited resources and considering service related constraints [9]. The problem consist of some parts of the component of a transit operational planning process which are setting frequencies, timetabling, assigning vehicles to trips and scheduling the drivers. In order to increase the system's efficiency and production, it is appropriate to treat all the components simultaneously. However, since the solution process is complex, it is desirable to solve it sequentially even though the optimality of the result is not assured [3].

Frequency setting described the regularity of bus departures on the routes at a time period. The inverse of frequency is headway which mean time period between two consecutive buses runs on the routes. The number of buses required to operate the entire network can be determined roughly. The frequencies can be calculated according to passenger's demand and the number of buses available. It can be constant or varies according to demand. Public demand can be found from point-check or ride check method. Timetabling is a process of determining departure times from each bus stop for every bus operating in the system. A timetable consist of departures times from all initial terminal, expected departure times from each bus stop on the route and expected arrival times at final bus stops. The product of derived frequencies and headways produced the timetable for transit system. Vehicle scheduling is the process of assigning the buses to specific timeslot with limited resources available. The exact number of buses required will be arranged accordingly. For driver scheduling, each of them is given a complete duty roster to work in their allocated buses [12].

The UTSP has been solved by different approaches based on the problem's complexity and constraints. The solution methods also changes according to the development of technology mainly the use of computer related programs and mathematical software.

3. Metaheuristic Approaches

Besides exact methods, metaheuristic approaches have been widely applied to solve the problem. These approaches are able to produce good quality output within reasonable time. Metaheuristic approaches explain general context that able to resolve various type of problems. They guide the search process and explore the search space to find optimal or near optimal solutions [13]. Metaheuristic approaches are suitable to solve UTSP especially those with large data sets. Moreover, it is also known for solving multiobjective UTSP since the era of 2000. Example of metaheuristic approaches are GA, Tabu Search (TS), Simulated Annealing (SA), Greedy Randomized Adaptive Search Procedure (GRASP), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bee Colony Optimization (BCO), and Local Search (LS).

Metaheuristics can be classified corresponding to its various properties. For instance, single-solution approach and population-based approach. Single solution approach can be categorized as a class of local search process that employ move-generation mechanism on attributes of single-solution which include TS, SA, GRASP, and LS. On the other hand, population-based approach uses a solution-generation mechanism which includes generation of new population and replacement of current population that functions on attributes of a set of solutions [14]. GA, ACO, BCO, and PSO are examples of population based methods. Hybrid and parallel metaheuristic also applied to improve existing solution procedure for producing innovative results.

3.1 Single-Solution Approaches
3.1.1 Tabu search

Cavique *et al*. [15] discussed the implementation of two heuristic algorithms based on TS in crew scheduling problem which are the tabu-crew algorithm and the run-ejection algorithm. The objective is to minimize the number of duties required to cover a predefined timetable under contractual rules without using extra time. First, run-cutting procedure is used to obtain initial solution and applied to a subset of problem in TS framework guided by strategic oscillation procedure. Second, block partition and matching algorithms are inserted in a tabu subgraph ejection chain to explore the neighbourhood. The computational result reflected that run-ejection algorithm gives superior performance in a case study.

Shen and Kwan [16] discussed a TS approach for transit driver scheduling problem. Initially, driver scheduling problem and its solution are explained. Then, Heuristic for Automatic Crew Scheduling (HACS) is applied. A TS technique with multi-neighbourhoods and suitable memory scheme is employed. Exploitation of the neighbourhood also designed. The algorithm is tested with real world data sets and able to produce comparable solutions when compared to mathematical programming approaches.

A multiobjective metaheuristic approach based on TS and GA has been developed to overcome the bus driver scheduling problem [17]. The problem is defined generally as a multi-objective set covering problem. The study also mentioned some measures of service quality that needed by different companies to be included in the objective function. The GRASP has been used as a step inside the metaheuristic methods. These algorithms are integrated in GIST Planning Transportation System and able to produce favourable solution for users. The TS outperformed the other methods as linear programming in term of cost, time and quality.

Gomes *et al*. [18] extended the studies of crew scheduling problem that previously cover the crew resources. The paper intends to balance the number of drivers and cover crews since the non-driving periods are usually longer than total duty time. A Lisbon Underground case study is used to demonstrate the crew timetabling problem. The problem is formed as multigraph representation and solved by TS.

Shen and Xia [19] presented a study of scheduling buses and drivers for the Beijing Bus Group Company based on unified mode of operation. Specific problems such as scheduling buses with built-in meal period, multi-type bus scheduling and restricting drivers to one or two particular buses are considered. The solution method consists of three main steps which are create a set of trip, build an initial schedule and refine the schedule. For bus scheduling, a 2-opt heuristic method, which is a type of mild descent neighbourhood search method is applied whereas for bus driver scheduling, TS-based constructive approach is used. This integrated bus scheduling system able to produce better results compared to existing system.

Chen and Niu [20] conducted a research on scheduling problem of urban bus crew based on impartiality. A crew scheduling model with the objective of minimizing total ideal time of a crew is constructed. The model is based on predefined transit timetables, large number of crews to satisfy the demand and maximum number of work hours for every crew. TS is applied to solve the optimization problem.

On the same year, Ruisanchez and Ibeas [21] constructed a bi-level optimization model to assign optimal bus sizes and frequencies to public transport routes. The upper level problem minimizes the cost of users and operators while the lower level model solved public transport assignment model subject to capacity constraint. The paper compared Hooke-Jeeves algorithm and TS algorithm using real-world problem. Both algorithms lead to similar solutions. However, TS converged quickly to optimal solution when the algorithms are started from the same homogenous solution.

Recently, Martínez *et al*. [22] compared exact and metaheuristic methods to study transit frequency optimization problem which is the time interval between subsequence buses for a set of transit given by itineraries. At first, a mixed integer linear programming formulation is used to solve small instances and TS method for larger instances. These approaches are tested on existing cases including real situations of a small city.

Overall, there are only few researches dealing with multiobjective problem which have more than two major objectives using TS. Apart from that, many authors focused only on transit driver scheduling by applying TS and none of the studies covered and solved all the UTSP collectively. In addition, the studies also failed to apply latest advancement in TS such as candidate list strategic, multiple TS and parallel TS to solve the UTS.

3.1.2 Local search

Guihaire and Hao [23] concentrated on quality of service in both network timetabling and vehicle scheduling by synchronizing the transfer, equalizing the line headways and optimizing number of vehicle needed based on resources. The transit network timetabling and vehicle scheduling problem are tackled simultaneously from the point of view of regulating authorities. Based on the exploration of two types of neighbourhood that intensify and diversify the search alternatively, an Iterated Local Search (ILS) is built to produce flexible decision aid tool. The experiment is carried out based on real transit network of large area and has been successfully integrated in a commercial software solution used for re-timetabling and scheduling by authorities.

Vanitchakornpong *et al*. [24] suggested a bus scheduling model with multi-depot and line change operations with the purpose of reducing the operating costs. Headways, travel time and route time restriction used as operational constraints. Constrained LS method is proposed to find better schedule. The procedure is experimented with the case study of Bangkok bus system and managed to reduce the operating cost as compared to the existing real system.

Silva and Reis [25] used two version of ILS to solve the crew scheduling problem. The classical ILS with the First Improvement method is tested. The classic improvement method conducts guided reallocation and exchange of crew tasks which replaces random component by finding suitable position to insert a task. Next, the ILS with Very Large-scale Neighbourhood Search is also tested to solve Brazilian large-scale problem. The results from ILS methods are compared to a variable neighbourhood search method.

There are possibilities to enhance the usage of LS method in solving UTSP since there is only one study for each of the frequency setting and timetabling, vehicle scheduling and transit crew scheduling problem, respectively. Apart from the basic LS and ILS, guided LS technique can be applied to solve the UTSP. Most of the studies seem to use first improvement method to explore the neighbourhood although there are other methods available such as best improvement method and intermediate option. Besides that, the perturbation process with different types of moves and strategies with various acceptance criteria as random walk can be included in LS algorithm to solve the UTSP.

3.1.3 Simulated annealing

Domschke [26] considered the problem of schedule synchronization for public transit by minimizing the waiting times at transfer stations. The paper tested various methods to compare the computing times and quality of the solutions. As a starting heuristics, modified version of rigid regret-heuristic method has been developed, applied and improved by Exchange Algorithm I and II. Besides that, SA and Branch-and-Bound (B&B) Algorithm also used to solve the model. The combination of Regret-Algorithm and Exchange Algorithm I give least computational time while the quality of solutions achieved by SA is depended on the parameters. The B&B Algorithm shows no possibility of solving large instances.

Daduna and Voß [27] studied the importance of schedule synchronization when constructing timetables. The main objective is minimizing the sum of all waiting times of every passenger at transfer node in a transit system. The constraints are based on complexity of existing network, different headways and origin-destination pairs of the demand structure. Maximum waiting time has been incorporated and interrelationship between service quality and operating cost are observed. A quadratic semi-assignment model is developed to formulate timetabling problem. Heuristic solution procedure is used due to the problem complexity. Regret heuristic is applied together with the SA and TS. The metaheuristic method clearly marks its advantage over previous procedure.

Zolfaghari *et al*. [28] derived SA algorithm with inhomogeneous approach and adaptive cooling technique that alter the control parameter according to the characteristics of the search trajectory. The algorithm is applied to find suitable holding strategies that minimize waiting time of passengers at all stops on the route. The algorithm able to improve the objective function value of benchmark case and the capability of solving the problem for all the buses on the route simultaneously is an advantage.

Zheng *et al*. [29] built Bus Optimization Scheduling Model with the objective of minimizing passengers waiting times and applied SA algorithm to solve the model. Actual operating data are used to verify the model and algorithm. The results show the algorithm produce more reasonable bus starting timetable.

Based on the literature, this method still suffers from some shortcomings in the UTSP. The SA can be used to overcome some subproblems in the UTSP as transit crew scheduling and transit scheduling. Besides that, most of the paper deals with single objective optimization problem but none has applied SA-based multiobjective algorithm such as Pareto Simulated Annealing for solving UTSP. Different types of algorithmic parameter such as annealing schedule also can be applied to study the UTSP.

3.1.4 Greedy randomized adaptive search procedure (GRASP)

Laurent and Hao [30] presented simultaneous approach to solve integrated vehicle and crew scheduling problem in extra urban transport. Single depot case with heterogeneous fleet of vehicles is considered for solving the problem. A constraint based model is solved initially by constraint programming techniques and consequently applied local search phase for neighbourhood exploitation. The analysis conducted on real world data reflects the effectiveness and flexibility of the approach.

D'Annibale *et al*. [31] studied the bus driver scheduling problem with the objective to determine minimum number of driver shifts subject to various regulations as overspread and working time. The combined heuristic of GRASP and rollout heuristic is proposed and tested for the problem. Computational results shows these randomized heuristic find near optimal solution.

De Leone *et al*. [32] addressed the problem of constructing good schedule for bus driver scheduling problem with the objective of minimizing the number of drivers required to cover a set of duty subject to special rules imposed by Italian transportation industry. In order to solve large size instances, a GRASP is applied. The outcomes are compared with exact method and effectiveness of the metaheuristic method is proved based on the numerical results. They also solved the bus driver scheduling problem with randomized multistart heuristic [33]. Several hybridizations of Reactive GRASP with Path-Relinking (PR) and Variable Neighbourhood Search are proposed to find quality solution with special constraints imposed by Italian transportation rules. The techniques have been tested both on Italian real-world instances and random instances.

More comprehensive studies are needed to explore GRASP in timetabling process and transit scheduling of UTSP. The effectiveness of GRASP can also be tested using the benchmark data rather than the real data sets provided by the company authorities. In addition, different adaptive functions can be used to execute the algorithm in the UTSP. The GRASP is yet to be applied in the multiobjective UTSP.

3.2 Population-Based Approaches
3.2.1 Genetic algorithm

Clement and Wren [34] applied a GA to bus driver scheduling problem. Special functions of GA have been developed that use constrained version of initial search space. Besides that, randomized greedy algorithm is used for crossovers. This greedy GA produced schedules within various bus driver working days of the optimal solution. Later, Wren and Wren [35] investigated the problem of creating daily schedules for public transport driver using a GA. A new crossover operator is developed that shows its effectiveness in producing feasible schedule in limited computational time. However, the paper suggested further investigations are required to overcome the real world problems.

Chakroborty *et al*. [36] analyzed a UTSP that minimizes the overall transfer time of transferring passengers and initial waiting time of the passengers waiting to board a transit at point of origin. A GA is applied to a number of test problems and found that it is able to give optimal schedule with reasonable computational resources. Deb and Chakroborty [37] presented a formulation to minimize the overall waiting time of transferring and non-transferring passengers by considering related restrictions. The problem is solved by a GA which control binary variables that act as transfer decision variable and also allow complex algorithm approaches to be manageable. Furthermore, capacity of solving the problems such as buses with limited capacity, improper timing of buses, and several stations transit system having common routes between bus stations shows the success of GA procedures.

Chakroborty *et al*. [38] also presented a simple binary coded GA based approach to optimize the fleet size distribution and scheduling with transfer consideration. The problem is formulated as non-linear mixed integer program and solved by a GA and it is proved in later research that exact procedures are not suitable to tackle the problem due to the reasons mentioned in [9]. The restrictions applied are total fleet size, stopping time, headways and transfer time. This method allows efficient modelling process and gives near-optimal result with limited computation effort although only single transfer stop with multiple lines is considered in the study. It is stated that this genetic representation will be difficult for large network.

Dias *et al*. [39] conducted a case study for bus driver scheduling problem by applying a GA to extend the approach of set covering problem. It allows considerations of various complex criteria and objective function that have important features of best solution. The GA also presented new coding scheme in relaxed partitioning problem. Its performance is tested with standard airline crew scheduling problem and real urban bus companies problems. GA shown satisfactory results near to planner's expectations.

Kidwai *et al*. [40] proposed a bi-level optimization model for bus scheduling problem where the main objective is to find a way to optimally distribute the buses among the routes. A two stage procedure is used. In the first phase, minimum frequency of buses per route by ensuring the load feasibility in each route is obtained. In the second phase, the bus size is further reduced by setting the fleet size from first level as upper bound and includes all the routes together. A GA is developed to solve the model and tested with road network in India.

Park [41] developed two computerized model which are simple GA (SGA) for deterministic arrival process and simulation-based GA (SBGA) for stochastic arrival process to optimize bus headways and slack times. The objective is to minimize the total system cost considering user and operator costs. The SGA is able to find solution quickly by using specific genetic operators such as coordinated headway generator, coordinated headway crossover and coordinated headway mutation while SBGA is capable of producing good result even with general genetic operators.

Sun *et al*. [42] emphasized the improvement of bus rapid transit operation quality. Specifically, the paper focused on headways optimization and scheduling combination of bus rapid transit vehicles with the objectives of minimizing passengers' travel cost and vehicles' operational cost. The constraints are time, frequency and passenger volume. The proposed model is solved by a GA of variable-length coding and proved scientifically feasible. Another research on optimizing public transport headways is investigated by Han [43]. The paper established a new model to maximise overall social benefits by GA. The method is applied to actual urban transit operations in Changchun city.

Yu *et al*. [44] presented a GA for bus frequency optimization. A bi-level programming model which find optimal bus frequencies aiming to minimize the total travel time of passengers subject to the constraints on the overall fleet size by accounting for the route choice behaviours of the passengers. Firstly, transit trips are assigned to bus route network based on optimal strategy followed by optimizing bus frequencies route as a result of passenger assignment. An iterative method, consist of a GA and a label-marking method is used to solve the model and improve the local service level of one company after the model is analyzed with two test examples.

Niu [45] focused on determination of the skip-stop scheduling for a congested transit line by a bi-level GA. A nonlinear programming model is built to minimize the overall waiting time and in-vehicle crowded costs subject to fixed number of vehicles and solved by the proposed algorithm. The outer GA is used to search the possible departure times at the terminal and the skip-stop operations are resolved by the inner GA. The validation of the model and algorithm are shown based on real-world case. The optimal schedule constructed has achieved the objectives when compared with regular schedule. Furthermore, Niu [46] also applied a GA to find transit schedule for urban public bus line under time dependent demand. A non-linear programming model with the objective function of minimizing overall waiting times at stations and crowded cost in vehicles. There are uneven vehicle-departure headways for the buses to operate and the possible departure times of vehicles are determined through a special binary coding method. For comparison, regular schedule with similar number of vehicles are created by simple computation and the proposed schedule reduced the overall waiting time and in-vehicle crowded.

Afandizadeh *et al*. [47] proposed a GA for bus planning process which includes network design procedure, frequency determination and assignment procedure and network evaluation procedure. The presented model also considers optimization of bus assignment at depots. Mandl's Swiss bus network is employed to test the model which later produced better results. Finally, Marshad bus network is planned using the proposed approach.

Based on current situation and operation environment, the effects of waiting time of passengers are taken into account [48]. A new fitness function is obtained by the penalty strategies and quantum GA that increases the global search capacity and convergence velocity is suggested in public transport dispatching problem. The algorithm solved the combining bus scheduling optimization effectively.

Zuo *et al*. [49] proposed a methodology to create Pareto solution for minimizing the number of vehicles and drivers to satisfy given schedule. Multiple block subsets are chosen from a set of candidate vehicle blocks by improved multiobjective GA with departure-time adjustment procedure. This approach applied in real world vehicle scheduling problem of a bus line in China that replaced previously used experience based solution. The study also shown initial start times based solution coding scheme which has short coding length and fast decoding and introduced population initialization method for quick converge to Pareto front. The method outperformed a standard GA, exact method and an experienced-based approach.

More recently. Nguyen and Phan [50] considered a scheduling problem for bus rapid transit routes. The problem is divided into normal scheduling, zone scheduling and express scheduling. The headway optimization and scheduling combination are measured. The proposed model modifies the existing model by improving the limitations. A GA is applied with various assumptions such as fixed headways, uniform passenger arrival rate, constant running speed and prioritized running lane. The model is applied to bus rapid transit in Hanoi and produced promising results.

To conclude, numerous efforts have been made in solving the UTSP by GA; yet only few studies have tackled the maximization problem. Further studies can be made by applying different GA parameters such as crossover probability, mutation probability and stopping criteria. Moreover, the decision variables for the UTSP model can be assigned using other type of values such as integer and real numbers besides the binary encoding.

3.2.2 Ant colony optimization

Yu *et al*. [51] optimized bus transit network by developing model with parallel ACO. The objectives are to achieve minimum transfers and maximum passenger flow per unit length with line length and non-linear rate as constraints. A heuristic pheromone distribution rule is applied, by which ants' path searching activities are altered based on the objective value. The model is validated with survey data of Dalian city. The algorithm optimizes bus network with less transfer and travel time besides increase the computational time speed and quality.

Wei *et al*. [52] proposed model and algorithm of regional bus scheduling with grey travel time. The paper aims to assign trips belonged to some routes to buses located at different depots to reduce the fleet size and operating cost. Several constraints such as multivehicle-type, depots capacities and fuelling are studied with consideration of emergencies in reality. The model is resolved by an improved ACO.

Additionally, Mazloumi *et al*. [53] studied the comparison of important features of ACO and GA in creating efficient transit schedule design of timing points for fixed route. The objective is to minimize generalized cost functions that include trade-off from various cost components. Location or number of timing points and amount of slack times for each timing points are act as decision variables. The sample data is derived from micro-simulation of bus route in Melbourne, Australia. In comparison, ACO approach shows higher efficiency by calculating less schedule designs to obtain optimal solution.

It can be clearly seen that no attempt is made to solve transit crew scheduling problem by ACO. Moreover, there is a lack of studies concerning the UTSP by multiobjective ACO approach. The two main iterated steps in ACO are solution construction and pheromone update. Various strategies could be used to update the pheromone such as online step-by-step pheromone update, online delayed pheromone update and off-line pheromone update.

3.2.3 Particle swarm optimization

In 2008, Fu and Lei [54] studied public transport dispatching problem by PSO with constriction factor and linear descend inertia weight. The economic efficiency and social benefits of transit agency are also included in balancing the concern of passengers and bus companies. The simulation results confirm its higher competency than other optimization techniques.

There is only one research focusing on transit dispatching problem in UTSP. Various sub-problems such as transit crew scheduling are yet to be explored by PSO. Numerous advances of PSO such as quantum-behaved PSO and different theoretical analysis for parameter selection can be applied to solve UTSP. Hybridization of PSO also still an open research area in UTSP.

3.3 Hybrid Approaches

The two schedule synchronization problems in public transport are studied to improve the transit network operational flexibility and efficiency. There are transfer synchronization at transfer points and harmonization of headways. This problem is formulated as a quadratic semi-assignment problem. An integrated TS and GA approach is proposed, with real world examples of tram lines from Cracow, to solve the problem. The quality of the transit service is improved by integration of service on schedule synchronization and effective dispatching control actions [55].

Park [56] suggested a hybrid genetic algorithm (HGA) by integrating with greedy interchange local optimization technique for studying vehicle scheduling problem with time deadlines and service due times. The minimization of fleet size, total vehicle travel time and total weighted tardiness are the conflicting objectives of this study. The algorithm used mixed farming and migration method with partially mapped crossover, newly developed mutation operators and two-chromosome genetic representation. Several types of test instances are analysed incorporating sensitivity analysis and better solutions are obtained compared to BCO.

Public transit vehicle dispatching problem is studied by considering the agency and passengers preferences [57]. A HGA that combined GA and SA is used to optimize the vehicle scheduling model. The algorithm indicates higher efficiency compared to simple GA.

Garcia [58] proposed intelligent methods to study bus driver scheduling problem for finding optimal shifts with minimal cost in temporary horizon using enough drivers to satisfy the demand. The problem is studied by metaheuristic methods which are GRASP and GA. The process of finding initial solution is divided into two and GRASP is applied in each of them. The output is then analyzed by the GA. The research is conducted for local public transportation company.

Application of adaptive GA can be observed in bus scheduling problem [59]. The algorithm used stronger local search ability and faster convergent speed in ACO to solve the problem. The operating cost, passenger's waiting cost and passenger's comfort degree are considered to formulate the model. The results produced shows high precision and efficiency in the model solution.

Li *et al*. [60] optimized multiple bus headways for a single bus route with a stochastic expected value model. There are two objective functions of the model which are maximization of bus company profit and minimization of passenger waiting time cost. The passengers' arrival, boarding or alighting and bus travel time that use Poisson, Binomial, and Uniform distributions respectively are randomized into the model. The problem is solved by hybrid intelligent algorithm in which GA and stochastic simulation are applied to handle the uncertain functions. Comparisons are done with traditional headways model using numerical experiments and this model is able to produce better results than existing models.

Schmid and Ehmke [61] integrated timetabling and vehicle scheduling problem with time window with the purpose of reducing cost of public transport operation by allowing small shifts of service trips' departure times and balancing the departure times to create quality timetable from the passengers' point of view. The two objectives are combined by weighted sum approach and solved by hybrid metaheuristic framework that decompose the problem into components which are scheduling service trips and balancing their departure times by desired interval. The scheduling component is solved by large neighbourhood search and the balancing work referred to simple linear programming method. The hybrid method improves the cost and quality of timetables.

Barbosa *et al*. [62] suggested an approach called SearchCol for hybridizing column generation, problem based algorithm and metaheuristics such as TS and SA. It is used to solve the given decomposition model for bus driver rostering problem by applying column generation procedure and to search the integer solution by metaheuristic approaches. Comparison between population-based approaches, evolutionary algorithms and single-solution approaches which are variable neighbourhood search and SA is conducted on the set of benchmark instances. The results show that good number of solutions produced by evolutionary algorithms.

Chen *et al*. [63] presented two models for optimizing school bus scheduling to cover all the stops within the school time windows by using bus type-based mixed integer programming formulation for both homogenous and heterogeneous fleet school bus scheduling. A hybrid metaheuristic method which combines LS with SA is used to solve the single-school bus routing and scheduling problem by minimizing total number of buses and total travel distance. The models are evaluated by benchmark datasets which shows the two-stage metaheuristic algorithm perform better than exact method.

Most recently, Ciancio *et al*. [64] proposed an integrated approach to solve two shift scheduling problem which aims to find a schedule for vehicles based on given set of rides and assign bus drivers to the vehicle schedules. Greedy algorithm is applied to obtain initial solution to overcome the Multi Depot Vehicle Scheduling Problem and the solutions are improvised by SA technique that exploits some LS methods. Next, the starting solutions for Crew Scheduling Problem are obtained by classical sequential algorithm. The algorithm managed to find good solutions with limited computational time for several numeral tests.

Based on the existing literature, the hybrid approaches using latest metaheuristic methods such as ACO, PSO and BCO are not explored in UTSP. Besides that, most of the hybrid metaheuristics in UTSP are performed sequentially. Parallel hybrid metaheuristics can be implemented in future. Different stages of hybrid metaheuristics which are high level or low-level relay and teamwork hybrid could be applied in UTSP.

4. Conclusions and Remarks

This review focused on UTSP especially buses by metaheuristic approaches. It begins by defining terms in UTNDP based on the classifications and presenting general overview on metaheuristic approaches. The reviews on UTSP using metaheuristic approaches by highlighting the possible gaps in each approach are given. Among them, population-based approach of GA is used extensively to overcome the scheduling problems. In UTSP, mostly transit crew or driver scheduling is studied as compared to frequency setting or transit scheduling problem.

As for future work, there is a need for more attention in numerous types of metaheuristic approaches for UTSP which are listed as follows:

- There is no research by latest nature-inspired population-based approaches such as BCO, BAT algorithm and Firefly algorithm for handling the UTSP. Most of the studies depend on the use of the usual approaches like GA and TS with different assumptions and criteria.
- Multiobjective metaheuristic method of both single-solution approach and population-based algorithm remain as an open research question except for TS and GA that have been applied in many researches for scheduling problem due to its flexibility and successful implementation experiences.
- Moreover, parallel metaheuristic approaches are rarely utilized in solving UTSP. This may be due to the problem complexity and cost of effective tools required for computation.

On the other hand, there are also some gaps with respect to the scheduling areas as listed below:

- Only few authors have tried to solve all the subproblems in UTSP concurrently by metaheuristics. Most of the formulation represent them sequentially to ease the problem solving process.
- Majority of the objectives include optimizing operational cost, waiting time, schedule synchronization and transfer. However, minimizing disruption to create robust timetables, minimizing emission of polluted gas and maximize passengers’ comfort while travelling in the transit

are seldom considered as main purpose. Furthermore, the use of different types of transit for scheduling is often overlooked.

- Usually, fixed demand throughout a week and even headways are considered for easy implementation. The demands can be varied according to day, time, and seasons throughout the year that depends on passengers' choice. Although variable headway is normally difficult to remember by passengers, but it shows quality timetables.
- Working preferences of the transit driver is also normally not taken into consideration to avoid unnecessary constraints that make the problem more complicated to solve.

As discussed above, the current literature of UTSP has a number of serious limitations that needs attention. More studies should test different types of approaches in dealing with UTSP to explore the effectiveness and filling the gaps in the respective methods. In addition, UTSP must be tackled from different perspectives by taking into consideration of small aspects in operational planning such as days of operation to create more realistic and ideal schedule.

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