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CASE STUDY AND REPORT

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Optimizing Schedules for School Bus Routing Problem: the case of Dar Es Salaam Schools

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Abstract: The School Bus Routing Problem (SBRP) deals with transportation of students to and from their schools. Given a set of fleet of buses of a school, a set of bus stops, the time matrix and the number of students at each stop, the task is to determine the schedule of buses that minimizes amount of time students spend in the buses on the way to and from school. The school bus routing problem is a special case of the Vehicle Routing Problem (VRP) and is known to be NP-hard. This NP-hardness implies that it is very unlikely that the problem can be solved in polynomial time. The common methods used to solve NP-hard problems are heuristic algorithms which gives quick and good solutions without guarantee that the solution obtained is optimal. In this paper a Tabu search based heuristic for SBRP is developed. The algorithm has been implemented using Borland C++ 4.5 programming language and tested using data from Tusiime Nursery and Primary School in Dar es salaam, Tanzania. The proposed implementation results in reduction of students' travelling time by 19.24%.

Keywords: Optimization, Bus Scheduling, Routing Problems, Tabu Search, Vehicle Routing

I. INTRODUCTION

The School Bus Routing Problem (SBRP) deals with transportation of students to and from their schools safely, in most economical way and in the most convenient manner. Given a set of fleet of buses serving a school, a set of bus stops, the time matrix and the number of students at each stop, the task is to determine the schedule of buses that can minimize amount of time students spend in the buses on the way to and from school. This involves the assignment of bus stops, students and routes to these buses. It is often the case that the routings are planned rather intuitively in real life, hence many parents complain that it takes their children much more travelling time than expected to reach at school and home [1].

In many cities students either walk to school or take public transport while some use school bus service (mini buses or large school buses). School bus is a type of buses designed for student transport. School bus service is the one that is committed to transport students to and from their school and in any school-related activities. This service can be offered by school itself or just co-ordinate as a middle-man and contract out to individual drivers or bus companies. The school buses are distinguished from other types of buses by colour necessitated by national regulations.

The school bus routing problem consists of two components; namely, routing and scheduling. In the case of routing, bus stops are planed first and each student is assigned to a certain bus stop. Individual bus stops are then combined to form a route. The scheduling component involves assigning particular buses to routes. In the morning bus k begin at route l travels along the route picking up students from stops and delivering them to schools. In the afternoon or evening (depending on the school timetable) the procedure is reversed, a bus picks up students at their school and drops off at their stops along the route [2].

In some schools, one bus can cover several routes in order to reduce the number of buses required. Their aim is to minimize the number of buses needed per day [3]. In this work we assume that the bus has only one route to deliver students to school/home place. The objective here is to design the quickest routes to and from the school so as to minimize students' total travelling time.

SBRP is a special case of the Vehicle Routing Problem (VRP) [4]. VRP is the problem of efficient use of a fleet of vehicles (e.g. trucks, buses and cars) that must make a number of stops to pick up and/or deliver passengers or products [5]. Since school buses have limited capacity, SBRP falls under Capacitated Vehicle Routing Problem (CVRP). The VRP is of great practical significance in real life. It appears in a large number of practical situations, such as transportation of people, collection of household waste, gasoline delivery trucks, delivery service, products distribution, mail delivery and garbage collection.

SBRP has attracted attention of many researchers since it was first proposed by Newton and Thomas [6]. The earliest studies on SBRP included; Angel et al [7], Bodin and Berman [8], Bowerman et al [9] and Braca et al [4]. More recent studies on SBRP are; Li and Fu [1], Schittekat et al [10], Bektas¸ and Elmastas [11], Fugenschuh [12], Martinez and Viegas [13] and Arias-Rojas et al [14].

SBRP is an NP-hard problem, [12] and therefore no algorithm is known that can solve it to optimality within reasonable time. Due to its NP-hardness many researchers use heuristics to solve SBRP especially for large instances. Corberan et al [15] adapted Scatter Search (SS) to solve the problem. Other researchers used Simulated Annealing (SA) and Tabu Search (TS) to improve initial solution for SBRP generated by insertion based heuristic [16], [17]. Recently, Arias-Rojas et al [14] used the Ant Colony Optimization to solve the problem.

There are some researchers who used exact methods to solve small instances of SBRP. Schittekat et al [10] developed a Mixed Integer Programming (MIP) model for the SBRP in Flemish region. They aimed to select a subset of stops that will actually be visited by the buses, determine which stop each student should walk to and develop a set of tours that minimize the total distance travelled by all buses. Bektas¸ and Elmastas, [11] presented an Integer Linear Programming model for the SBRP. Their objective was to minimize the total bus travel costs. Martinez and Viegas, [13] presented an alternative mixed integer linear programming formulation of a single school in Lisbon. They aimed to minimize the daily operational costs of the service which derive from the number of buses used for the service and the total travel time, constrained to the service specification. Comprehensive survey on SBRT can be found in Park and Kim [18].

In this paper, we present a Tabu Search heuristic in order to produce good quality solutions to the real-world school bus routing problem faced by schools in Dar es Salaam. We have chosen to use Tabu Search heuristic because it has been shown in literature that it is one of the most used meta heuristic algorithms for wide range of optimization problems. We utilize an objective function to measure the total time spent by students in travelling to or from their school. The algorithm was implemented in Borland C++ 4.5 and using secondary data from Tusiime Nursery and Primary School in Dar es Salaam, Tanzania.

II. SCHOOL BUS SCHEDULING IN DAR ES SALAAM

Dar es Salaam is among the rapid growing cities in Africa [19]. Expansion of the city has posed challenges in terms of city planning, regulation and provision of urban transport services [20]. Some students in Dar es Salaam walk to school, however, majority of students are using public transport called "daladala" to and from their schools. Other students are using school bus service and the majority of these schools are privately run. The school buses are distinguished from other types of buses by yellow paint with black writings "School Bus". The buses are equipped with specific warnings and safety devices.

Students transport in Dar es Salaam is a chronic problem which hinders students' academic progress as well as causing some other social problems such as teen pregnancies and other delinquencies such as student fighting with daladala conductors [21]. The daladalas various sized minibuses provide virtually all urban passenger transport and in the absence of a regulation agency, tend to focus on the most profitable lines as well as on the most profitable clienteles. School children who pay a lower fare are being refused at rush hours in favour of more profitable clients, [22].

These schools take students from different areas in Dar es Salaam. Locations of students are scattered and the routing is planned manually. Some schools plan their routes according to experience of the driver, condition of the road and condition of the bus. Long routes are given to the most experienced drivers while other drivers are assigned to shorter routes. Some schools plan their routes according to driver's house (for those buses with parking places near driver's houses), their routes starts at parking places.

III. PROPOSED SOLUTION

A. *Tabu Search Algorithm:*

Tabu Search (TS) heuristic was proposed by Glover [23]. TS belongs to the class of meta-heuristics, which are approximate algorithms used to obtain good enough solutions to hard combinatorial optimization problems in a reasonable amount of computation time. The method uses a local search or neighbourhood search procedure to iteratively move from a solution to another until some stopping criterion has been satisfied. This algorithm uses short-term memory called *tabu list* to keep some attributes of recent solutions in order to avoid moving towards them for a specific number of iterations called *tabu tenure*. The TS algorithm starts at some initial solution S and then move to a neighbouring solution S'. A neighbouring solution is generated by a set of admissible moves. At every iteration of the algorithm, an admissible best move is applied to the current solution to obtain a new solution to be used in the next iteration. A move is not applied even if it is an improving one if it is in the *tabu* list. The moves are performed with the aim of reaching a good solution by evaluation of objective function $f(S)$.

Tabu Search based algorithms have been applied in many combinatorial optimization problems because they usually provide solutions very close to optimality [23]. A pseudo-code in this work is presented in the Figure 1, Where S_0 is the initial solution; S is Current solution, S_{Best} is the best solution found so far; TL is the Tabu list and $N(S)$ is the set of candidate neighbours of S.

```
BEGIN
Get Initial Solution
Set ; ;
WHILE (k<MaxIteration) Do
Generate set
Choose a candidate solution
such that
f(S') ≤ f(S"
IF
ENDIF
Push into
Set
Update
END WHILE
Return as the best solution
END
```

Figure 1: A pseudo-code for Tabu Search Algorithm

B. *Mathematical Formulation:*

The following are the sets that are used in the model formulation:

a. $N = \{0, 1, 2, \dots, n\}$ is the a set of all bus stops where students are picked up, where n is the total number of stops arranged scattered around the school and 0 denotes the school.

b. $V = \{1, 2, \dots, K\}$ is the set of the available buses to be used. K is the number of available buses.

The decision variables used in the model formulation are as follows:

c. X_{ijk} is a binary variable that identifies if bus stop i precedes bus stop j in the route serviced by bus k. That is, $X_{ijk} = 1$ if bus stop i precedes bus stop j in the route operated by bus k and 0 otherwise

d. Z_{ik} *is* a binary variable that identifies if bus k picks students at stop i.

e. Y_{ik} is an integer variable that represents the number of students that are picked up at stop i by bus k.

The proposed model uses the following parameters;

f. T_{ij} represents the travel time from stop i to stop j.

g. C_k denotes the capacity of bus k.

h. L is the average pick up time at each stop.

i. L_i is the number of students at stop i.

a) Objective Function: The objective function f of the model calculates the total travel time spent by students in all points. Thus, the aim of the model is to minimize f. The total travel time spent by students in all points comprises of the total travel time TT from one stop to another and the total pick up time PT.

The total travel TT is given by the sum of travel time from stop i to stop j multiply by the sum of stops that bus k picks up students for each *i*. Thus, TT is given by:

$$TT = \sum_{k=1}^{K}\left\{\sum_{i=0}^{n}\left[\sum_{j=0}^{n} T_{ij} X_{ijk}\left(\sum_{l=0}^{i} Z_{lk}\right)\right]\right\}.$$

The total pickup time is given by the sum of average pickup time multiply by the sum of stops that bus k picks up students for each stop i. This is given by;

$$PT = \sum_{k=1}^{K}\left\{\sum_{i=0}^{n} LZ_{ik}\left(\sum_{l=0}^{i} Z_{lk}\right)\right\}.$$

The objective function is given by;

$f = TT + PT$.

Therefore, the objective function of the model becomes:

$$\text{Min } f = \sum_{k=1}^{K}\left\{\sum_{i=0}^{n}\left[\sum_{j=0}^{n} T_{ij} X_{ijk}\left(\sum_{l=0}^{i} Z_{lk}\right)\right]\right\} + \sum_{k=1}^{K}\left\{\sum_{i=0}^{n} LZ_{ik}\left(\sum_{l=0}^{i} Z_{lk}\right)\right\}$$

b) Constraints: The objective function f is subjected to the following constraints;

(a). The first constraint is on the bus capacity. This ensures that the sum of students picked up by bus k in all points should not exceed the bus capacity. This is given by:

$$\sum_{i=1}^{n} Y_{ik} \le C_k \quad \forall k \in V.$$

(b). Next we need ensure that all students are picked up. i.e., the sum of students picked up by all buses at point i should be equal to the number of students at that point. This gives:

$$\sum_{k=1}^{K} Y_{ik} = F_i \quad \forall i \in N.$$

(c). Next we ensure that the number of students picked up by bus k should not exceed the number of students at that point. Thus we have:

$$Y_{ik} \le F_i Z_{ik} \quad \forall i \in N, \forall k \in V.$$

(d). Finally, we have to ensure that if a bus picks up students at a point it must also visit that point. This is represented by:

$$\sum_{j=0}^{n} X_{ijk} \ge Z_{ik} \quad \forall i \in N, \forall k \in V.$$

C. Tabu Search Implementation:

a. The Initial Solution

A Tabu-search based heuristic needs an initial solution as its input (S_0). It is therefore necessary to have an easy and quick way of generating an initial school bus scheduling solution. In this work an initial solution is generated as follows: The first bus is assigned to pick students at the first stop and then to the next stop in ascending order until it is full. The next bus starts to the following non-visited stop following the same procedure until all students have been picked up.

b. The neighbourhood structure:

Neighbourhood structure is used to determine a pool of neighbouring solutions in which one is to be picked (move) for the next iteration. In general, for any specific problem at hand, there are many possible neighbourhood structures. Therefore, a suitable neighbourhood structure for this problem must be well defined.

In SBRP, 2-opt, 1-1 opt and 1-0 exchange are possible moves for a neighbourhood. The 2-opt exchange consists of the set of all solutions that can be obtained from the current solution by exchanging two stops on the same route. The 1-1 exchange move involves interchanging two stops from different routes (one from each route). This will maintain the number of stops in the route. In the 1-0 exchange move a stop is removed from its original route and is inserted in a random selected route. In this work we have used 1-1 exchange approach because it involves moving a stop in one route to another and cannot change the number of stops of the bus.

c. The Tabu List (TL):

Tabu list (TL) is used to store some attributes of recently visited solutions in order to prevent the process from cycling in the small set of solutions. This prevents their occurrence for a certain period called tabu tenure. The tabu tenure is an important factor to guide the search. It influences the performance of the method.

Salhi, [24] provides three approaches for defining tabu tenure; fixed to a predetermined value, randomly chosen from a specific range, or dynamically changing by adjusting the value. In this work, a predetermined fixed value is examined. Before choosing the fixed value, the experiment of varying tabu tenure was carried out to choose the best tabu tenure [25]. The experiment involves testing several numbers, tabu tenure is increased when the same solution is visited over and over and is decreased when no duplicate solution has been marked for some time. In this work we used tabu lists of size 3, 5 and 10.

d. The Termination Criteria:

Since tabu search is an iterative search method, it can execute to infinity. So we need to include termination criteria. These criteria depend on the algorithm used in solving the problem. The algorithm can terminate if; the objective function reaches a pre-specified threshold value, no feasible solution in the neighbourhood of the solution (neighbourhood is empty), no changes in the solution for a number of iteration, or the specified number of iteration is reached. However, the pre-specified number of iterations approach has a disadvantage that the algorithm can run for a long time without improvement just to complete the set of iterations. Thus, in this work we have considered the number of iterations without a change in solution value as the termination criterion. We let the algorithm stop if it runs for 50 iterations without improvements.

IV. PROPOSED SOLUTION

A. Current Implementation:

Tusiime Nursery and Primary School has 15 identical school buses, each with capacity of 34, to service 456 students from different parts of Dar es Salaam in 58 bus stops. The locations of students are scattered and that the current routing is planned manually. The current manual implementation results are indicated in Table 1. The table shows the bus number, the number of students to be served and the students' total travelling time of each bus as drawn from experience in the system.

Table 1: Total time spent by each bus before implementation of the algorithm

Bus No	No. of Students	Time (Min)
1	32	95
2	33	113
3	31	101
4	29	125
5	32	102
6	30	108
7	28	130
8	30	84
9	32	106
10	29	116
11	28	135
12	33	78
13	26	109
14	30	87
15	33	83
Total	**456**	**1572**

The travel time estimation between each pair of stops was done by consulting school bus drivers. The average pick up time for all stops is considered to be L = 2 minutes.

B. Summary of Results:

The algorithm was implemented using C++ programming language. We ran the algorithm on a 2GHz machine with 1.87 GB RAM and Windows 7. The penalty function was introduced in the program to penalize the solution that violates the constraints.

The program was executed a number of times to get an optimal solution. After getting the optimal solution, the total time spent by each bus was recorded in the Table 2.

Table 2: Results of total time spent by each bus after implementation of algorithm

Bus No	No. of Students	T (Minutes)
1	30	45
2	33	76
3	30	75
4	34	85
5	30	82
6	26	70
7	27	54
8	33	121
9	34	80
10	31	94
11	27	88
12	25	64
13	27	106
14	34	97
15	34	131
Total	456	1268

The comparison of time spent by each bus between manual and the proposed computer solution is shown in Figure 2.

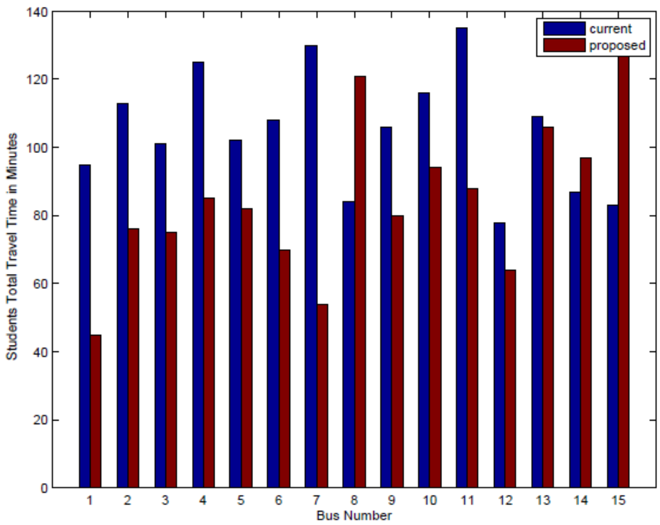

Figure 2: Comparison of travelling times between the current and proposed solution

Comparing data in Table 1 and Table 2 we see that the total travelling time by students has been reduced from 1572 to 1268 minutes. Hence, the model results into a reduction of students' travelling time by 19.33%, which is significant.

V. CONCLUDING REMARKS AND FURTHER STUDIES

The aim of this work was to design and implement a Tabu-search based algorithm for the school bus routing problem. We have used real data from Tusiime Primary School from Dar es Salaam in Tanzania as a case study. To the authors' best knowledge, this is the first study that is based on heuristic algorithms approach in schools in Tanzania. The results obtained shows that students travelling time can be reduced by 19.33% if the algorithm is applied by the school.

The results obtained can be extended to other schools in Dar es Salaam. As a suggestion for further studies therefore, more data can be collected from other schools which may provide different features and challenges to be addressed. Furthermore, the formulation presented in this study can accommodate several additional constraints like time window constraints, limits on the capacity of the buses (lower and upper limits on the number of students per bus) or upper and lower bounds on the distance each bus can travel. Therefore, it would be interesting to investigate the impact of adding these additional constraints.

The study has been able to show that heuristic algorithms can be used in Tanzania to improve performance in school bus scheduling and contribute tremendously the efficiency in the transportation sector.

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