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Multi-objective optimization model formulation for regional bus scheduling problem

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Abstract: In this paper we present a model for scheduling and routing of regional passenger's buses in Tanzania. A multi-objective optimization model for scheduling of the regional passenger's bus routing problem was formulated where by a mixed-integer programming was used to address the conflicting objectives of maximization of profit and minimization of the running costs. The set of real data collected from SUMATRA, EWURA and buses companies in Arusha were used as model input parameters. The analysis of the model was carried out to determine how the routes provide maximum profit and minimize running costs also the lexicographic goal programming method has been employed to solve the proposed model. Based on the analysis and cost dealings, best routes were selected. The results show significant improvements and cost savings for the regional passenger's bus transport system.

Keywords: regional bus routing; multi-objective optimization; lexicographic goal programming.

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1. Introduction

Transport is an essential tool in helping the creation of a single socio-economic space that would result to free movement of goods and persons. Transport service industry comprises of several modes which range from air, water, railways, pipelines and road transports. Road passenger transport is now identified as one of the most important means of facilitating movement of people and parcels in the country. Furthermore, people are now depending much on road transport due to the poor condition of other inland transport systems notably railways. The significant role played by this mode of transport is due to its accessibility, flexibility and affordability to most of the Tanzanian citizens. For many years, the transport sector in Tanzania has helped to increase access to farming implements, movement of farm products, integrate markets, strengthening competition, tourism, foreign investment, promote trade, and has contributed to government revenues [1]; [2] . How to transport passengers to and from their designated terminals is an important question facing many bus companies and managers and hence needs a careful and planed schedule of different routes. Bus scheduling is a process that deals with the proper assignment of buses to a given route to serve the expected daily passenger demand. Using too many buses incurs additional operational cost to the company and using too few buses will decrease the service quality and increases the waiting time of passengers at the bus stops [3].

For a long time, most passenger road transport companies in Tanzania have got poor performance in operation and even some of them failed totally to operate their business activities due to various problems. Example Kamata, Scandinavia, Zafanana, Mwanahapa, Kibo, Lang'ata, Summry just to mention few are no longer operating due to various problems [1]. [4] elaborates that performance of passenger’s road transport services for many companies in Tanzania is continued to be provided with significant high costs and not systematically planned. The bus routing problem is one of the major problems facing many bus companies and managers in the world. In many cities in Tanzania such as Dar es Salaam, Arusha, Mwanza, Tanga and Mbeya, most companies that provide this service have inadequate knowledge on how to route and schedule their buses. This problem has lead managers into failure of managing the locations of bus as the results unsuccessful satisfactions of the customer's needs in the transportation market. There are a number of studies have investigated on scheduling of vehicles for public transportation systems. However, among those studies the problem on how to route and schedule their buses has not received much consideration. [5] presented a model and related analysis for scheduling and routing of public buses in Kuwait. The approach used is simpler and more realistic for applying the model to real problems of public transportation planning problems. The linear programming model is developed to determine the optimal number of seats required for the selected routes at a given time slots. [6] have developed a new intercity bus schedule for the Saudi Public Transport Company (SAPTCO) model for maximize profit and yield additional revenue, were the main objectives was to evaluate the maintenance and the operations department through developing a new fleet assignment model (new bus schedule). The model proposed a new assignment system which considers maximizing the utilization of any bus in the fleet. The study done by [7], developed the heuristics approach for solving a largescale vehicle-scheduling problem with route time constraints. In their work a new formulation for multi depot vehicle scheduling (MDVS) and multi depot vehicle scheduling problem with route time constraints (MDVSRTC) have been proposed. [8] proposed a linear programming model for the bus scheduling problem specifically for Kuwait Public Transport Company (KPTC) the aims were to improve current scheduling operations, reducing the running costs of different routes with better service to the passengers and increasing their efficiency, for each time slot the linear program was applied separately and then combined the results into a final solution. In addition, the model appeared to be very helpful in defining optimal number of assigned seats per route per time slot.

The multi-objective mixed integer linear programming model based on Tchebycheff methods for VRP with a heterogeneous fleet was proposed by [9], in which the objectives of the model were to minimize the total internal costs, while minimizing some environmental considerations as the CO_2 and NO_X emissions. The results showed a positive contribution towards a more sustainable balance between economic, environmental and social objectives. Computational results show good quality solutions for the heuristic. [10] proposed a mixed integer multiple commodity network flow problem to produce timetables and bus routes/schedules for inter-city bus carriers with the aims to maximize the profits. In the study by [11] a mixed integer mathematical model for the integration of Anbessa city bus and Addisababa light rail transit was formulated, the objective of their study was to maximize number of simultaneous arrivals. The results showed that the proposed model reduces waiting time by decreasing headways to achieve synchronization. [12] formulated a multi-objective mathematical model for urban school bus routing problem (USBRP). The objectives of the model were to minimize the bus route distance, to balance student walking distance with bus route distance, and to perform both load-balancing and length-balancing between the routes. The model appeared to be very helpful in consideration of student walking distance and load-balancing. Among those studies the problem of minimization of route cost has not received much consideration. In this study, we considered the bus routing problem faced by regional bus passengers in Arusha city, which has 19 bus routes that connect different parts from Arusha city to different cities of Tanzania together with different bus companies operating in these routes. In this paper, we present a multi-objective optimization model and goal programming algorithm that will maximizing the total profit and minimizing total internal costs in order to improve current scheduling operations and reduce the total running cost with better service to the passengers.

2. Problem Formulation

The regional bus passenger routing problem was formulated as a Multi-objective Optimization Problem (MOOP) with two conflicting objectives these are, maximization of profit and minimization of running costs. The model contains of the uncertainties of the problem (the decision variables), the known data (the parameters), the control of the system (the constraints) and two optimization drivers (objective functions).

Model Assumptions

The assumptions of the model are:

(i) No bus can exceed its capacity and each customer is picked at the original node.

(ii) The nodes are predetermined

(iii)Routes must also meet a maximum allowable driving time per day

(iv)The passenger carrying capacity of bus is based on the international bus carrying capacity

(v) Bus must depart from and return to the original node

(vi)Every bus can be assigned to any routes without considering route characteristics such as distance

(vii)Normal maintenance costs are assumed to be fixed

Notation of the Mode

Indices	Description
i	Origin Index, $i = 1,2, \ldots, I$
j	Destination Index, $j = 1, 2, \ldots, J$
k	Buses Index, $k = 1,2,, \ldots, K$

2.1 Decision Variables of the Model

The decision variables in the model are the quantities of transportation of customer from original node to destinations.

Table 1 define the decision Variables and description.

Variable	Description
A_{ijk}^{k}	Binary variable, equal to 1 if bus k ϵ {1… K} travels from original node i to destination node j (i≠j).
U_{ij}	1 if bus k picked customer from node i to node j by some bus, 0 otherwise.

2.2 Parameters of the Model

The parameters are the recognized values (data) that are required by the model as an input to calculate the decision variables. These parameters are as defined in Table 2

Table 2: Parameters and description.

$Parameter$	Description
L_k	Average number of customers for bus k in original node
x_{ij}	distance from original node i to destination node j
T^k	maximum allowable driving time in hours for bus k
P^k	Pay of driver for bus k per unit time.
cf	unit cost of fuel in Tshs per route per day
V_{ij}^k	Load carried by bus
V	Load carried by bus
r	The bus capacity
fx^k	the fixed cost of bus k
mn^k	costs of preventive maintenance, repairs and tires per km of bus k
tc_{ij}	Costs of tolls from original nodes i to destination node j
q	the revenue collected from the customer (fares customer pays)
β	the unit traveling cost
W	Minimum number of passengers by destination node j
μ	the bus capacity

2.3 Objective Function

The multi-objective optimization problem formulated in this research consists of two objective functions, this are: Maximizing Total Net Profit (max TNP) and Minimizing the Total Internal Costs (min TIC) in cost of running buses (cost of drivers, energy costs, fixed cost of vehicles–depreciation, inspection, insurance, maintenance costs and toll costs) from planning routing in Passenger buses.

(i) Total Net Profit

The Total Net Profit (TNP) $= Total\ profit\ collected - Total\ cost\ of\ traveling$

Therefore, the objective function is given as follows:

Maximize TNP = $\sum_{i \in N \setminus \{0\}} q_{ij} L_k u_{ij} \quad - \beta \sum_{i \in N} \sum_{\substack{j \in N \\ i \neq j}} x_{ij} L_k A_{ijk}$

(ii) Total Internal Costs

Minimization of all variable costs incurred in (TZS). The variable costs in running buses includes: cost of drivers (CD), energy costs (EC), fixed cost of buses–depreciation (FC), maintenance costs (MC) and toll costs (TC).

$TVC = CD + EC + FC + MC + TC$

The objective function is given as follows:

$$\text{Minimize TIC} = \sum_{k=1}^{K} p_{ij}{}^{k} A_{ijk}^{k} + \sum_{i=0}^{I} \sum_{\substack{j=0 \\ j \neq i}}^{J} \sum_{k=1}^{K} cf_{ij} x_{ij} A_{ijk}^{k} + \sum_{i=1}^{I} \sum_{k=1}^{K} fx_{k}{}^{k} A_{ijk}^{k} + \sum_{i=0}^{I} \sum_{\substack{j=0 \\ j \neq i}}^{J} \sum_{k=1}^{K} mn_{j}{}^{k} x_{ij} u_{ij}^{k} + \sum_{i=0}^{I} \sum_{\substack{j=0 \\ j \neq i}}^{J} \sum_{k=1}^{K} tc_{j} A_{ijk}^{k}$$

2.4 Model Constraints

The greatest combination of the decision variables A_{ijk}^{k} and U_{ij} is found with respect of the defined constraints or limitations. In this paper the constraints of the system are as follows:

Ensures that a customer has no incoming and out- going arcs unless it is visited:

$$\sum_{\substack{j \in N \\ j \neq i}} u_{ij} = \sum_{\substack{j \in N \\ j \neq i}} u_{ji} \qquad i \in N$$

Each bus departs from the original node once or doesn't, which means no more than k buses (fleet size) depart from the node:

$$\sum_{j=1}^{J} A_{ijk}^{k} \geq 1 \,; \quad (k = 1, \ldots, K)$$

Flow conservation on each node:

$$\sum_{\substack{j=0 \\ j \neq 1}}^{J} A_{ijk}^{k} - \sum_{\substack{j=0 \\ j \neq 1}}^{J} A_{kji}^{k} = 0 \quad (k = 1, \ldots, K; \;\; i = 1, \ldots, I)$$

Ensure that no bus can be overloaded:

$$\sum_{j=1}^{J} A_{ijk}^{k} \leq r_k \,; \quad (k = 1, \ldots, K)$$

Restrict average number of customers from original node to the destination in a specific route:

$$\sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} L_k = \mathrm{W}_{jk}; \quad (k=1,\dots,K;\ \ i=1,\dots,I)$$

Restrict the total load a bus carries depending on whether it arrives or leaves a customer:

$$L_k \sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} \leq \sum_{\substack{k=1\\ k\neq 0}}^{K} v_k^k \quad ; \ (k=1,\dots,K;\ \ i=1,\dots,I).$$

3. Lexicographic Goal Programming Formulation

In goal programming formulation, the decision-maker orders the priority of the objective functions. The core objective of Goal Programming is to concurrently satisfy a number of goals relevant to the decision-maker. Firstly, the problem is solved for the top most importance objective first, and then this value is never allowed to get worse. The problem is solved for the following priority and so on, until the problem is solved.

3.1 Preemptive Goal Programming: Is a special case of goal programming in which the goals are divided into sets and each set is given a priority; i.e., first, second, third, and so on. The concept is that a higher priority goal is considered as more important than a lower priority goal. Then, for each priority, a target value is determined and the deviation variables are introduced. These deviation variables may be positive or negative (represented by d_i^+ and d_i^-). The positive deviation variable d_i^+ represents the quantification of the over-achievement of the i^{th} goal while the negative deviation variable d_i^- represents the quantification of the under-achievement of the i^{th} goal.

Lastly for each priority, if the desire is to overachieve then, minimize d_i^+ or if underachieve then, minimize d_i^-, or if to satisfy the target value exactly then minimizing both d_i^+ and d_i^- is expressed as shown in Table 3.

Table 3 Procedure for Achieving a Goal

Minimize	Goal	If goal is achieved
d_i^+	Minimize overachievement	$d_i^+ = 0, d_i^- \geq 0$
d_i^-	Minimize underachievement	$d_i^- = 0, d_i^+ \geq 0$
$d_i^+ + d_i^-$	Minimize both overachievement and underachievement	$d_i^+ = 0,\ d_i^- = 0$

The solution is attained by initially optimizing with respect to the first-priority goals without regard to the values of lower priority objectives. Then, holding constant the value of the first-priority objective function, the optimal solution is obtained for the second-priority goals. The feasible solution space for this second problem is the set of alternate optima for the first problem. The process continues until all priorities are considered. If no alternate optima exist at the end of a particular stage, we have reached the end of the computations, so we must be satisfied with the current values of the lower priority objectives [13]:[14]:[15].

3.1.1 Formulation of the First Objective

Min TNP = $\beta \sum_{i \in N} \sum_{\substack{j \in N \\ i \neq j}} x_{ij} L_k A_{ijk} - \sum_{i \in N \setminus \{0\}} q_{ij} L_k u_{ij}$

with other Constraints:

$$\sum_{\substack{j \in N \\ j \neq i}} u_{ij} = \sum_{\substack{j \in N \\ j \neq i}} u_{ji} \qquad i \in N \tag{1}$$

$$\sum_{\substack{j=0 \\ j \neq 1}}^{J} A_{ijk}^{k} - \sum_{\substack{j=0 \\ j \neq 1}}^{J} A_{kji}^{k} = 0 \quad \left(k = 1, \dots, K;\ \ i = 1, \dots, I\right) \tag{2}$$

$$\sum_{\substack{j=0 \\ j \neq 1}}^{J} A_{ijk}^{k} L_k = \mathrm{W}_{jk}; \ \left(k = 1, \dots, K;\ \ i = 1, \dots, I\right) \tag{3}$$

$$\sum_{j=1}^{J} A_{ijk}^{k} \geq 1; \quad \left(k = 1, \dots, K\right) \tag{4}$$

$$\sum_{j=1}^{J} A_{ijk}^{k} \leq r_k; \quad \left(k = 1, \dots, K\right) \tag{5}$$

$$L_k \sum_{\substack{j=0 \\ j \neq 1}}^{J} A_{ijk}^{k} \leq \sum_{\substack{k=1 \\ k \neq 0}}^{K} v_k^k \quad ; \left(k = 1, \dots, K;\ \ i = 1, \dots, I\right) \tag{6}$$

Solve the above Objective and get $G_1 = z_1^* =$ value 1.

3.1.2 Formulation of the Second Objective

$$\text{Min TIC} = \sum_{k=1}^{K} p_{ij}{}^{k} A_{ijk}^{k} + \sum_{i=0}^{I}\sum_{\substack{j=0\\ j\neq i}}^{J}\sum_{k=1}^{K} cf_{ij} x_{ij} A_{ijk}^{k} + \sum_{i=1}^{I}\sum_{k=1}^{K} fx_k{}^{k} A_{ijk}^{k} + \sum_{i=0}^{I}\sum_{\substack{j=0\\ j\neq i}}^{J}\sum_{k=1}^{K} mn_j{}^{k} x_{ij} u_{ij}^{k} + \sum_{i=0}^{I}\sum_{\substack{j=0\\ j\neq i}}^{J}\sum_{k=1}^{K} tc_j A_{ijk}^{k} + d_1^{+} + d_1^{-}$$

Subject to the Constraints:

$$\text{Min TNP} = \beta \sum_{i\in N}\sum_{\substack{j\in N\\ i\neq j}} x_{ij} L_k A_{ijk} - \sum_{i\in N\setminus\{0\}} q_{ij} L_k u_{ij} - d_1^{+} + d_1^{-} = z_1^*$$

with other Constraints:

$$\sum_{\substack{j\in N\\ j\neq i}} u_{ij} = \sum_{\substack{j\in N\\ j\neq i}} u_{ji} \qquad i \in N \tag{1}$$

$$\sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} - \sum_{\substack{j=0\\ j\neq 1}}^{J} A_{kji}^{k} = 0 \quad (k = 1,\dots,K;\ i = 1,\dots,I) \tag{2}$$

$$\sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} L_k = \mathrm{W}_{jk};\ (k = 1,\dots,K;\ i = 1,\dots,I) \tag{3}$$

$$\sum_{j=1}^{J} A_{ijk}^{k} \geq 1;\quad (k = 1,\dots,K) \tag{4}$$

$$\sum_{j=1}^{J} A_{ijk}^{k} \leq r_k;\quad (k = 1,\dots,K) \tag{5}$$

$$L_k \sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} \leq \sum_{\substack{k=1\\ k\neq 0}}^{K} v_k^k \quad ;\ (k = 1,\dots,K;\ i = 1,\dots,I) \tag{6}$$

$$d_1^{+}, d_1^{-} \geq 0.$$

Solve the above Objective and get $G_2 = z_2^* =$ value 2.

3.1.3 The Lexicographic Goal Programming is formulated as follows:

Min Z=$d_1^{+} + d_2^{+}$

Subject to the Constraints:

$$\text{Min TNP} = \beta \sum_{i\in N}\sum_{\substack{j\in N\\ i\neq j}} x_{ij} L_k A_{ijk} - \sum_{i\in N\setminus\{0\}} q_{ij} L_k u_{ij} - d_1^{+} + d_1^{-} = G_1 = z_1^* = \text{value 1}$$

$$\text{Min TIC} = \sum_{k=1}^{K} p_{ij}{}^{k} A_{ijk}^{k} + \sum_{i=0}^{I}\sum_{\substack{j=0\\ j\neq i}}^{J}\sum_{k=1}^{K} cf_{ij} x_{ij} A_{ijk}^{k} + \sum_{i=1}^{I}\sum_{k=1}^{K} fx_{k}{}^{k} A_{ijk}^{k} + \sum_{i=0}^{I}\sum_{\substack{j=0\\ j\neq i}}^{J}\sum_{k=1}^{K} mn_{j}{}^{k} x_{ij} u_{ij}^{k} + \sum_{i=0}^{I}\sum_{\substack{j=0\\ j\neq i}}^{J}\sum_{k=1}^{K} tc_{j} A_{ijk}^{k} + d_1^{+} + d_1^{-}$$

$= G_2 = z_2^* =$ value2

with other Constraints

$$\sum_{\substack{j\in N\\ j\neq i}} u_{ij} = \sum_{\substack{j\in N\\ j\neq i}} u_{ji} \qquad i \in N \tag{1}$$

$$\sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} - \sum_{\substack{j=0\\ j\neq 1}}^{J} A_{kji}^{k} = 0 \quad \left(k = 1,\dots,K;\ \ i = 1,\dots,I\right) \tag{2}$$

$$\sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} L_k = \mathrm{W}_{jk};\ \left(k = 1,\dots,K;\ \ i = 1,\dots,I\right) \tag{3}$$

$$\sum_{j=1}^{J} A_{ijk}^{k} \geq 1\,; \quad \left(k = 1,\dots,K\right) \tag{4}$$

$$\sum_{j=1}^{J} A_{ijk}^{k} \leq r_k\ ; \quad \left(k = 1,\dots,K\right) \tag{5}$$

$$L_k \sum_{\substack{j=0\\ j\neq 1}}^{J} A_{ijk}^{k} \leq \sum_{\substack{k=1\\ k\neq 0}}^{K} v_k^k \quad ;\ \left(k = 1,\dots,K;\ \ i = 1,\dots,I\right) \tag{6}$$

$$d_1^{+}, d_1^{-},\ d_2^{+}, d_2^{-} \geq 0.$$

4. Results

The analysis of the model was done by the lexicographic goal programming algorithm where by in this method first, the problem is solved for the first priority goal for our case is maximization of profit, and then its value is never allowed to deteriorate. Then the problem is solved for the second priority goal which was minimization of running costs.

The model is developed in GLPK Integer Optimizer version 4.57 using GLPSOL (LP/MIP) solver and performed on an Intel(R) Core (TM) i5-7200U CPU@2.50 GHz Dell Laptop computer with 4 GB of RAM. Goals for the preemptive goal programming model are provided in Table 4 along with their results, and the priority of each goal.

Table 4. Goals for the Preemptive Goal Programmings

Objective	Goal	Results	Priority
Maximize	Profit	15,094,100	1
Minimize	Running costs	6,465,098,615	2

The model has been run and an integer optimal solution found and the output is displayed within few seconds. Table 5 shows the outcomes of the last formulated objective function in which all deviation variables are zero, this means that all goals are perfectly satisfied.

Table 5. Deviation Variable Values

Deviation Variable	Values
d_1^+	0
d_1^-	347,759,000
d_2^+	0
d_2^-	17,479,100

The values for all objective functions are shown in Table 6 which gives the maximum profit and minimum running costs for both objectives, the best value was determined to be Tsh 15,094,100/day and Tsh 6,465,098,615/day respectively.

Table 6. Objective Function Value

Priority Goal	Objective Function	Values
1	Z_1	Tsh. 15,094,100
2	Z_2	Tsh. 6,465,098,615
	Z	0

Also 9 routes selected are more profit among 19 routes, table 7 show the results. With regard to the values of the objective functions the proposed system shows good performance in the rise profit by 15%, furthermore a reduction in the running costs by 17.16% as compared with the current existing situation of scheduling and routing system used by bus companies. We recommended the management of bus companies to adopt the proposed system because the findings from the study show that the new model gives better performances on the total profit and reduction on the running costs as compared with the existing situation of scheduling and routing system which are used by bus companies.

Table 7. Routes selected which are more profit

Regional Centre's Routes		
From	To	**Status from analysis**
Arusha	Moshi	Selected
Arusha	Babati	Selected
Arusha	Singida	Not Selected
Arusha	Tanga	Selected
Arusha	Dodoma	Not Selected
Arusha	Morogoro	Selected
Arusha	Dar es salaam	Selected
Arusha	Shinyanga	Selected
Arusha	Tabora	Not Selected
Arusha	Mwanza	Not Selected
Arusha	Iringa	Not Selected
Arusha	Musoma	Not Selected
Arusha	Lindi	Not Selected
Arusha	Bukoba	Not Selected
Arusha	Kigoma	Not Selected
Arusha	Mtwara	Selected
Arusha	Mbeya	Selected
Arusha	Songea	Selected
Arusha	Sumbawanga	Not Selected

5. Conclusion

The aims of this work were to formulate and analyze the multi-objective optimization model for scheduling of the regional passenger's bus routes problem. The developed model has two main conflicting objectives these are, maximization of profit and minimization of running costs for regional passenger’s bus. The multi-objective optimization model for scheduling of the regional passenger's bus routes problem was solved by the lexicographic goal programming method. Firstly, the problem is solved for the most important goal, and then its value is never permitted to be worsen. The problem is solved for the next goal and so on until the problem is solved. The model was applied with the use of the real data collected from SUMATRA, EWURA and buses companies in Arusha. Sensitivity analysis will also be conducted to assess major model parameters such as the effect of changing unit travel costs as well as variable costs in order to advice bus owner and decision makers.

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Conflict of Interests

The authors declare that there is no conflict of interests.

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