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RESEARCHARTICLE

# OPTIMAL PASSENGER DEMAND ON BUS RAPID TRANSIT IN TANZANIA A Case of Kibaha– Gerezani Route

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**ABSTRACT**

This paper examines the effect of optimal Passenger demand ($P^*$) in Transport services using Mathematical model. Numerical analysis of the model shows that the increase in BRT frequency $f_r$ trigger decrease in passengers' cost $C_P$, as well as total cost $C_T$ that is combination of operation and passenger costs. The passenger cost increases at the beginning and gradually starts to decrease as well as total $C_T$. In fact, operation cost increases as frequency increases due to fuel consumption, turn out of tires and bus services. Meanwhile, when using optimal passenger demand, passengers' cost and operation cost are decreasing they exist because, as optimal passenger demand $P^*$ increases, BRT frequency also increases and therefore, waiting time is reduced for all passengers. However, operation cost is fixed like paying salary of staff, bus services and other office expenses, but this should be devastating by members of staff to work hard, use of the bus effectively and ensure getting optimal passengers so as to get operation cost and the profit, otherwise the bus will run with loss. From these findings indicate that BRT management should make effort to attract all passengers by reducing value of average waiting time and BRT service ($\phi_1$), value of waiting time ($V_w$) and the average time getting on and out of the bus per passenger ($A_{ou}$).



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# INTRODUCTION

Passenger, defined in this paper as a person who is traveling from one place to another in a *Bus Rapid Transit* (BRT) and who is not driving or working on it. It is unlikely that mobility will become completely private in the near future, because of the inevitable traffic congestion and difficulties of storing individual vehicles when they are not in use. In other words, even though technological development may transform the appearance of BRT transport, the fundamental challenge of coordinating individual travelers who share vehicles of high capacity will remain. Efficient resource allocation is critical in its daily operations. Therefore, BRT transport has been among the most popular subjects in transport economics since the infancy of this discipline. The purpose of BRT transport economics is to make this coordination more efficient, ensuring optimal resource allocation to unlock all societal benefits of mass mobility as per Horcher¨ and Tirachini's (2021) statement. In developing countries, cities provide better opportunities for living like chance of getting job of high salary, pursuit of higher studies than in urban areas, however inequality is a problem facing the world community (Ali *et al.* 2022, Lagakos 2020 and Abdoulaye NGOM 2024). Therefore, urban internal migration rate that involves movement (from rural to urban) and birth rate are significantly higher than in developed countries, as in Rees *et al.* (2017) and Farrell (2017). Furthermore, the Nations and U. World Urbanization Prospects 2018 argue that Urbanization growth is considered a factor in economic growth, poverty reduction and human development. The gap between urban and rural living standards increases the rate of rural–urban migration. According to Parmar *et al.* (2020) urban population growth increases the population density, transportation demands, infrastructure development costs such as parking space. The rapid development of Dar es Salaam city is one of the essential issues of the 21st century. According to the latest census of 2022, there is rapid increase in the population to more than six million of people living in the city. Immigration and birth rates are two main factors in increasing the population of Dar es Salaam City, this is as a result people move from Dar es Salaam City center to Coast Region for example Kibaha township. In this regard increase the demand of Transport and other social well-being. In recent years, using BRT has been considered a new solution in Tanzania since 2016 in Dar es Salaam city and then extended to Coast Region specifically Kibaha township since 2021, now it semes to be not comfortable to most of the passenger in term of waiting time. BRT management believe that increasing frequency of a scheduled transport service, is typically expensive in terms of operational costs. However, since people's time is valuable, reducing the frequency of such services may also be costly in terms of waiting times for passengers. The outcome of the social welfare-optimal BRT frequency is an important task that seems to have received too little attention in practice as in Massa we and Makinde (2023). This study addresses this question and exploring methods that are suitable for the case of BRT service. This study finds the simplest model that is appropriately describe the given optimization problem. Mathematical model of the square-root rule is planned, and their precision is examined and compared with that of previous version of Mohring (1972).

**Model Formulation and Analysis**

**Optimal Model on a Single Line**

In formulating the model, the following assumptions are considered

- Access time costs is not included as the distance between stops is not an optimization variable in this model.
- Bus stop location is fixed.
- Bus capacity is 80 passengers which work for 18 hours a day.
- BRT carry passenger every after 15 minutes.
- Distance from kibaha to Dar es Salaam (Gerezani) is 37 kilometers, which uses 1hour and 20 minutes from Kibaha to Gerezani
- Total passenger demand along the route is more than 19,440.

The total cost of BRT service is comprised of operator and passengers cost as follows

$$B_{ct} = B_c N + V_a t_{ap} + V_w t_{wp} + V_{Is} t_p \quad (1) \qquad (1)$$

where $B_c$ is the cost per BRT unit [Tshs/veh-h], N is the number of vehicles [veh],$t_{ap}$, $t_{wp}$and $t_P$ are total access, waiting and in-vehicle times of passengers and$V_a$,$V_w$and $V_{IS}$ are the values of access, waiting and in-vehicle time savings respectively. Vehicle cost $V_C$ can be modelled as a linear function of vehicle capacity □, as estimated in Tirachiniet al (2022), and Massawe and Makinde (2023).

$$V_C = V_{C_0} + V_{C_1} K \quad (2) \qquad (2)$$

Navy scope N is the total cycle time $t_c$, times the BRT service frequency $f_r$ [veh/h]. Cycle time is composed of hurrying and slowing down at stops, pedestrian crossing, traffic light and passengers delay on getting on and getting out of the bus at their destinations $R_t$. If P is total demand [trips/sec.] and $A_{ou}$ is the average time for getting on and out of the bus per passenger, then cycle time is:

$$t_c = R_t + A_{ou} \frac{P}{f_r} \quad (3) \qquad (3)$$

where $\frac{P}{f_r}$ is the average number of passengers per vehicle. Therefore, the bus operation cost is:

$$C_{0p} = \left(V_{C_0} + V_{C_1} K\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) f_r \quad (4) \qquad (4)$$

If $\phi_1$ is the fraction between the average waiting time and BRT service and $\phi_2$ is the fraction of average trip length to the total route length, then passengers' cost is:

$$C_P = \left(V_w \phi_1 \frac{P}{f_r} + V_{Is} \phi_2\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) p \quad (5) \qquad (5)$$

In this case the behavior of BRT operation and passenger can be investigated for their effect on the value of $\phi_1$. On other side, if movements are large and a timetable of bus schedule is presented, then passengers adjust their behavior and arrive at bus stops a few minutes before scheduled bus arrival as in Massawe and Makinde (2023). Finally, if $\delta$ is the fraction between the extreme passenger load of the route and the total passenger demand along the route, then the vehicle capacity is directly obtained from service frequency as follows:

$$K = \delta \vartheta \frac{P}{f_r} \qquad (6)$$

In (6), for the determination of vehicle size, parameter $\vartheta$ is introduced to have extra space to carry passengers in the middle stations and to allow those who have reached their destination in the middle stations to get out of the bus comfortably with slight time spent as in Tirachini et al. (2022) , and Masawe and Makinde (2023). Total cost has the following form:

$$C_T = C_{0P} + C_P$$

$$C_T = \left(V_{C_0} + V_{C_1} K\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) f_r + \left(V_w \phi_1 \frac{P}{f_r} + V_{Is} \phi_2\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) p$$

$$\therefore C_T = \left(V_{C_0} + V_{C_1} \delta \vartheta \frac{P}{f_r}\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) f_r + \left(V_w \phi_1 \frac{P}{f_r} + V_{Is} \phi_2\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) p \qquad (7)$$

By differentiating (7) with respect to Passenger demand P, The square root formula for optimal Passenger demand is obtained as:

$$C_T = \left(V_{C_0} + V_{C_1} \delta \vartheta \frac{P}{f_r}\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) f_r + \left(V_w \phi_1 \frac{P}{f_r} + V_{Is} \phi_2\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) p$$

$$\frac{d}{dP}\left(\left(V_{C0} + V_{C1} \delta \vartheta \frac{P}{f_r}\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) f_r + \left(V_w \phi_1 \frac{P}{f_r} + V_{Is} \phi_2\right)\left(R_t + A_{ou} \frac{P}{f_r}\right) p\right)$$

$$\text{Then } P^* = \frac{-f_r g + \sqrt{f_r^2 \left\{g^2 - 3 A_{ou} V_w \phi_1 \left(A_{ou} V_{co} + R_t \left(\delta \vartheta V_{C1} + V_{Is} \phi_2\right)\right)\right\}}}{3 A_{ou} V_w \phi_1}$$

$$P^* = \frac{f_r \sqrt{\left\{g^2 - 3 A_{ou} V_w \phi_1 \left(A_{ou} V_{co} + R_t \left(\delta \vartheta V_{C1} + V_{Is} \phi_2\right)\right)\right\}}}{3 A_{ou} V_w \phi_1} - f_r g$$

$$\text{Thus } \quad P^* = \frac{f_r}{3 A_{ou} V_w \phi_1}\left(\sqrt{\left\{g^2 - 3 A_{ou} V_w \phi_1 \left(A_{ou} V_{co} + R_t \left(\delta \vartheta V_{C1} + V_{Is} \phi_2\right)\right)\right\}} - 3 A_{ou} V_w \phi_1 g\right)$$

$$\text{where } \quad g = R_t V_w \phi_1 + A_{ou} \left(\delta \vartheta V_{C1} + V_{Is} \phi_2\right)$$

Optimal total passenger demand $P^*$ increases with the increase of BRT service frequency and decreases with the fraction between the average waiting time and BRT service ($\phi_1$), value of waiting time ($V_w$)and the average time forgetting on and out of the bus per passenger ($A_{ou}$).

**Table 1. Parameter description and estimated values**

| Parameters | Parameter description | Parameter estimation |
|---|---|---|
| P | Passenger demand | 0.3Trip/sec |
| $\phi_1$ | Fraction between average waiting time and BRT service | 0.33/h |
| $\phi_2$ | Fraction of average trip length to the total route length | 0.22/km |
| $V_{C0}$ & $V_{C1}$ | Bus cost | 0.38&0.4$ |
| $V_w$&$V_{IS}$ | Value of waiting and in-vehicle time serving | 0.11&0.01per hour |
| $A_{ou}$ | average time getting on and out of the bus per passenger | 0.19per hour |
| $R_t$ | hurrying and slowing down at stops, pedestrian crossing, traffic light and passengers delay on getting on and getting out of the bus at their destinations | 0.21 per hour |
| $f_r$ | BRT service frequency | 0.25veh/h |
| $\vartheta$ | Extra capacity to absorb random variations on demand | 0.12per vehicle |
| $\delta$ | Ratio between the extreme passenger load of the route and the total passenger demand along the route, | 0.296trip/h |

**Model Analysis**

The model system of equations (4,5,7 and 8) will be examined to get better understanding of the effects of BRT service frequency on the passenger demand. Parameter values are estimated to vary within realistic means and as shown in table 1.

**Explanation of the parameter values**

Passenger demand, P is 0.3/sec that is,18 passengers demand the bus every after one minutes with the total of19,440 $(0.3\times 60\times 18hrs\times 60)$ the whole day but the BRT bus can carry only 5,760 that is $\left(\frac{18hrs\times 60\min utes}{15\min utes}\right)\times 80\,bus\ capacity$ this due to the fact that this parameter depend on the values of other parameters, means that, other parameters values when they are high or low, increases the value of P (Passenger Demand) for example the fraction between average waiting time and BRT service $\phi_1$ is 0.33/h which means that, the average waiting time is 20 minutes for buying ticket and waiting for the bus. The parameter $\phi_1$ should be reduced by increasing the BRT service so as to increase passenger demand. Also, the ratio of average trip length to the total route length, $\phi_2$ is 0.22 per km, this implies that one bus has 8 trips a day that is 0.22x 37km= 8 means that, four turnaround trips which reduce BRT frequency and hence affect passenger demand. Not only this but also bus cost, $V_{C0}$&$V_{C1}$ are 0.38&0.4$respectivelywhich is equivalent to Tshs950/= and Tshs1000/=compared to the cost of 1450/= from Kibaha to Gerezani or from middle stations which is high, the cost should be reduced to attract more passengers and also those in the middle station can pay according to the distance from their destination to Gerezani. Furthermore, value of waiting and in-vehicle time serving, $V_w$&$V_{Is}$are0. 11&0.01per hour that is 6.6 minutes is waiting time and 0.6 minutes is time serving for the Bus, this depends on the passenger ending and getting on the bus. The parameter $V_w$ should be less so as to serve more time for passenger. The average time for getting on and out per passenger, $A_{ou}$ is 0.19/hour means that 11.4minutes of time is used for getting on and out per passenger to the middle stations along the road. More than that hurrying and slowing down at stops, pedestrian crossing, traffic light and passengers delay on getting on and out of the bus at their destinations, $R_t$ is 0.21per hour, means that 12.6 minutes of the time is waste due to delay on the road this shows that measure can be done to reduce this, like recording voice which will tell the passenger the near station and the alighting passenger to move to the near door. On top of that BRT service frequency $f_r$ is 0.25per hour, means that BRT buses take passengers after every 15 minutes, where passenger can use 2hours and 5 minutes instead of 1 hour and 20 minutes from Kibaha bus terminal to Gerezani terminal - Dar es Salaam that is 15minutes waiting for the bus , 12.6 delay due to hurrying and slowing down at stops, pedestrian crossing, traffic light and passengers delay on getting on and out of the bus at their destinations $R_t$, 6.6 minutes in bus waiting time $V_w$ and 11.4 minutes of time is used for getting on and out of the bus to the middle stations along the road which make total of 45.6 minutes delay minus 0.6 minutes time serving which will be 45 minutes, time wasted along the road. Another parameter is extra capacity to absorb random variations on demand, $\vartheta$ and its value is 0.12 means that BRT should have minimal extra capacity of 10(0.12x80=9.6~10) passengers as to take those who will have demand on the way to the destination and also to have a space of those who have reached their destination to move out the bus comfortably. Lastly the ratio between the extreme passenger load of the route and the total passenger demand along the route, $\delta$ is 5760/19440=0.296 means that time used to carry passenger is 18 hours a day which is equivalent to 1080 minutes a day and the number passenger load of the bus is 80,means that the passenger carried along the route is (1080 / 15) 80 = 5,760 which is the passenger travel from Kibaha to Gerezani but there are more passengers along the route from kibaha to Gerezani about 19,440. This shows that there is a need to take measure so as to carry all the passengers especially those who are at the middle stations like Njiweni, Sheli, Mpakani, Kiluvya Madukani, Gogoni, Kibamba Shule, Kibamba Hospitali, Kwa Mangi, kwakomba, Magarisaba, St. Joseph and kwa Yusufu when the BRT is from Kibaha to Gerezani.

**Numerical Simulation and Results**

Analytical results are shown by carrying out numerical simulations of the model equations4,5, 7 and 8. Parameter values are estimated to vary within realistic means as shown in (9).

$$V_{C0}=0.38, V_{C1}=0.4, \vartheta=0.12, \delta=0.296, f_r=0.25, R_t=0.21, A_{ou}=0.19, \phi_1=0.33, \phi_2=0.22, V_{Is}=0.01, V_w=0.11, P=0.3 \quad (9)$$

The overall dynamic of models is presented in Figure 1.It was observed that as increasing BRT frequency $f$ tends to decrease passenger cost $C_P$, as well as Total cost $C_T$, $C_P$ increase at the beginning and then start to decrease as the frequency increasing. In fact, operation cost $C_{op}$, increases as frequency increases due to fuel consumption, turn out of tires and bus services.

Meanwhile the optimal passenger demand (P*) is decreasing, because, as optimal passenger demand increases, BRT frequency also increases and therefore, waiting time is reduced for all passengers, then also cost per BRT is reduced as the bus, staff members and other office expenses are used effectively with a profit

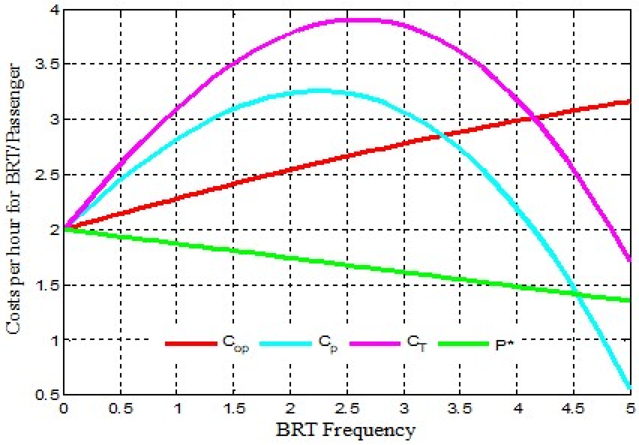


**Figure 1. Costs per hour for BRT/passenger against increasing values of BRT frequency $f_r$**

# DISCUSSION AND CONCLUSION

This paper examines the effect of optimal passenger demand (P*) in Transport services using Mathematical model. Numerical analysis of the model shows that increasing BRT frequency $f_r$ tends to minimize passenger cost $C_P$ and total cost $C_T$. Passenger cost increase at the beginning and gradually start to decrease, as well as $C_T$, which is a combination of both operation and passenger costs. In fact, operation cost increases as frequency increases due to fuel consumption, turn out of tires and bus services. Meanwhile when using optimal passenger demand, passengers' and operation cost is decreasing, since, as optimal passenger demand increases, BRT frequency also increases and therefore, waiting time is reduced for all passengers, that makes the bus run with profit. Thus, BRT management should put more effort by reducing waiting time in buying tickets, waiting time for the bus in the station, wasting time forgetting on and out of the bus to the middle stations along the road. In fact operation cost is fixed like paying salary of staff, bus services and other office expenses, but this should be devastating by members of staff to work hard, use of the bus effectively and ensure getting optimal passengers so as to get operation cost and the profit, otherwise the bus will run with loss.

# CONCLUSION

Optimal Model on a Single Line was presented based on four equations; BRT operation cost, passenger cost, total cost and the optimal passenger demand. Simulation shows that optimal passenger demand P*reduce passenger cost and BRT operation cost.

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