FORMULATION OF A BUS DISPATCHING POLICY TO ACHIEVE SIMULTANEOUS ECONOMIC AND FINANCIAL OPTIMIZATION OF A ROUTE

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ABSTRACT

The problems of scheduling and schedule co-ordination have conflicting objectives related to user’s cost and operator’s cost. Passengers would like to have public bus service where there is less waiting time. Operators on the other hand would like to have profit with lesser vehicle operating cost and a minimum number of buses. When we consider the service of buses, passengers would like to have less crowding in buses but operators would like to have higher load factors to increase revenues.

In this paper we attempt to consider both user’s cost and operator’s cost in order to optimize both. Costs have two parameters economic and financial costs. Ideally both should be optimized at the same time. For passengers their costs are constituted by waiting and standing costs. For operators, their costs would be the operating costs namely number of trips they do for a day. Optimum economical headway for a bus would be the headway where the total economic cost to both passengers and operators is a minimum. However, the operators will try to maximize his financial revenue to coincide with the economic optimum.

This paper discuses two methods to achieve this. One method is to increase financial revenue to the operator by increasing fares or by providing some percentage of revenue to operator by the government. Second method is to remove taxes on inputs to bus operation or to provide subsidies to operator to reduce financial cost to the operator. Using these two methods conjoint optimality could be reached.

INTRODUCTION

Dispatching of buses on a route is a vital element of a good bus service, whether the private sector or the government operates it. Buses could be dispatched according to two general criteria, i.e. economic and financial. Under economic criterion, buses would be dispatched considering the economic benefit to the country as a whole. Under financial criterion, only the financial benefit to the operator is considered.

When reviewing past studies in this area such as Newell’s Dispatching Policy (Newell, 1971), Vickery (Vickery, 1955) and Mohring’s Dispatching Policy (Mohring, 1955), and Hurdle’s Dispatching Policy (Hurdle, 1973), most of the dispatching rates determined in these studies are based on variables of passenger demand rate, value of passenger waiting time and the economic cost of operating buses on the route. In these studies, the emphasis has been made to determine a dispatching policy aimed at fulfilling demand without ensuring the financial viability of the operators. This is appropriate for situations wherein either the State sector provides all bus services or the private sector is reimbursed for its costs. But in an environment such as is presently seen in Sri Lanka, where the private sector has to ensure financial viability dispatching policy based on purely economic rationale is not practicable.

If we examine closely the currently practiced method of dispatching buses in Sri Lanka, it is based on maximizing the revenue for the service provider often at the expense of the quality
of the service anticipated by the passenger. That is the bus is loaded to maximize the revenue to the operator at the expense of increasing waiting time and discomfort to the passenger. In many cases this leads to negative effects to the country’s economy such as loss of time and fatigue of the passenger that leads to lower productivity and economic activity.

The studies mentioned above have another deficiency in application to Sri Lanka that is they have assumed that every passenger is seated. But in a country like Sri Lanka, this is not the case. Many passengers travel standing and therefore when dispatching buses, the economic cost of discomfort (increased fatigue) due to standing must also be considered (Kumarage et al, 2001). Therefore the past studies on bus dispatching can not be directly applied in Sri Lanka.

In this paper an attempt has been made to include the economic cost of standing as well as to relate both the financial and economic cost considerations in the provision of bus services on a particular route.

**ECONOMIC COST OF ALL PASSENGERS FOR A ROUTE FOR A DAY**

This paper assumes the economic cost to a passenger to be composed of the cost of waiting and cost of standing. The cost of the ticket is ignored, as it does not vary with the dispatch rate. Economic cost to passengers would be zero if buses were dispatched as soon as each passenger arrives. This is not practical as the cost to the operator would be prohibitive (actually it is then a taxi service). In reality buses are dispatched from time to time and the intervening period is referred to as headway. Passengers therefore have to wait that length of time and their economic cost would increase as headway increases. If the bus continues to fill even after all seats are occupied then those passengers have to travel standing. In this situation, the service these passengers get would be less than what they pay for in terms of their having to suffer economic loss due to the fatigue of standing throughout the journey. This amount could possibly increase exponentially with time as the discomfort of standing increases with the time they have to stand.

In calculating the economic cost to the passengers, following assumptions were made. The entire traffic day on an entire route and for simplicity in analysis, a route where all passengers board at the starting terminal and alight at end terminal- that is there are no intermediate stops. Then we observe that the number of passengers standing in a bus can be found from the relationship

\[
\left( D - \frac{C}{h} t_d \right) \quad \ldots \ldots (1)
\]

where,

\begin{align*}
    h & \quad \text{– average headway} \\
    D & \quad \text{– average demand of boarding per route per day} \\
    C & \quad \text{– average seats per bus and} \\
    t_d & \quad \text{– length of traffic day.}
\end{align*}

The headway at which passenger would begin to start to travel standing if identified as \( h_0 \) can be calculated as
Assuming passengers arrive at the boarding terminal at uniform rate with respect to time, the variation of economic cost to passenger could be mathematically expressed as:

\[ h_0 = \frac{C}{D} t_d \quad \ldots \ldots (2) \]

Economic Cost to Passengers

\[
ECP = \begin{cases} 
  h < h_0 & \frac{1}{2} h \gamma_c D \\
  h > h_0 & \frac{1}{2} h \gamma_c D + \left( D - \frac{C}{h} t_d \right) t_s \gamma_s 
\end{cases} \quad \ldots \ldots (3)
\]

Where,
- \( \gamma_c \) – average cost of waiting per passenger per unit time
- \( \gamma_s \) – average cost of standing per passenger per unit time and
- \( t_t \) – average time per trip from terminal to terminal.

This variation in economic cost to passengers is depicted in Figure 1.

**Figure 1. Economic Cost For Passengers For Route For A Day**

**OPERATING COST OF BUSES IN A ROUTE FOR A DAY**

The financial cost to all the operators of buses on a route for a traffic day can be given by the equation

\[
Financial \ Cost \ to \ Operators = (FCO) = \left( \frac{t_d}{h} \right) e_f \quad \ldots \ldots (4)
\]
Where $C_f$ is the financial cost of operating a single trip from one terminal to another. The corresponding economic cost of bus operations to the country can be given by the equation

$$Economic\ Cost\ of\ Operation\ = (ECO) = k_{sp} \left( \frac{t_d}{h} \right) C_f \quad \text{……..(5)}$$

where $k_{sp}$ is the shadow price factor on economic inputs when they are taxed $k_{sp} < 1$ and when they are subsidized by the government $k_{sp} > 1$. When this equation is closely analyzed it can be observed that the economic cost of bus operations would decrease exponentially with headway and increase linearly with increasing trip time. This is shown in Figure 2.

**Figure 2. Economic Cost To Operator For A Route For A Day**

**ECO** – *Economic Cost to Operator*

**DISPATCHING ON ECONOMIC CRITERIA ONLY**

If the total economic cost of the route, to the country is given by the equation

$$f_{tec} = f_{ecw} + f_{eco} \quad \text{……..(6)}$$

where the economic cost to the passengers and economic cost of bus operations are represented by the functions $f_{ecw}$ and $f_{eco}$. The total economic cost is shown in Figure 3. As shown in most past studies such as Newell’s Dispatching Policy (Newell, 1971) the most
economic dispatching headway would be the headway that has the minimum total economic cost. This is given as \( h_e \) when headway is

\[
\frac{d(f_{ecw})}{dh} = 0 \quad \text{or} \quad \frac{d(f_{ecw} + f_{eco})}{dh} = 0
\]

Cost
(Rs. / Day)

Figure 3. Economic Bus Dispatching

Where,

- **ECP** – Economic Cost to Passengers (Waiting and Standing Costs)
- **ECO** – Economic Cost of Bus Operations
- **TEC** – Total Economic Cost

**DISPATCHING ON FINANCIAL CRITERIA ONLY**

We can similarly construct the basis on which financially derived headway is arrived at. This can be done by calculating the total financial cost and the financial revenue to the operator, of operating the route over a traffic day.

The financial revenue from bus operations on the route during the period, is given by the expression

\[
\text{Financial Revenue to Operator} = \text{FRO} = k_t f_t D_{rt} \quad \text{………(7)}
\]

Where,

- \( f_t \) – revenue per passenger per boarding and
- \( k_t \) – constant depicting the ratio of the length of travel of each passenger to the total route length so that \( k_t \leq 1 \).
- \( D_{rt} \) – Total Demand for Boarding per Day
It can be seen that the financial revenue to the operator is independent of the headway, as it is fixed on a route. The constant $k_t$ depends on the type of a route. For a terminal to terminal non-stop operation as assumed in this analysis $k_t = 1$ and for other routes where passengers alight at intermediate stops $k_t < 1$. Variation in financial revenue to operators, is therefore a horizontal straight line as it is independent of headway, as shown in Figure 4.

Where,

- **ECO** - Economic *Cost of Operating*
- **FRO** - Financial *Revenue to Operator*

If we make a further assumption that the financial cost to the operator is equal to the economic cost, then the financially viable headway for an operator is $h_f$. The economic cost at this headway ($h_e$) would be not optimal. Figure 4 shows a simplified situation where only financial costs are considered.

**DISPATCHING ON ECONOMIC AND FINANCIAL CRITERIA**

Figure 5 shows the superimposed costs –economic and financial.

If our objective it to ensure that the dispatching rate can achieve both economic and financial optimization of costs simultaneously then we need to have a joint optimality condition where $h_e$ and $h_f$ coincide or at least are as close as possible to each other. Two different strategies can be shown to achieve this.
Strategy I

Increasing the amount of financial revenue to the operators is the first strategy. Two methods could be applied for this strategy. One is to increase the unit fare paid by the passenger and the other is to provide some percentage of financial revenue to the operator by the government as a subsidy.

**Method A:** The first method is to increase the bus fare by percentage $\Delta f$, whereby total revenue is increased to match the cost so that $h_e = h_f$. Therefore,

$$FRO' = (1 + \Delta f/100) \times FRO$$

$$FRO' > FRO$$

Due to the elasticity in demand, when fares are increased revenue would be slightly less than the above calculated value. Effects of this are shown in Figure 6.

![Figure 5. Financial And Economic Bus Dispatching](image)

**Figure 5. Financial And Economic Bus Dispatching**

![Figure 6. Effects Of Revenue Increase](image)

**Figure 6. Effects Of Revenue Increase**
**Method B:** The second method could be applied when fare increases is not a viable solution due to affordability, or other reasons. This is by providing some percentage of financial revenue or subsidy to the operator by the government so that the revenue to the operator is increased. This we shall refer to as a fare subsidy as the subsidy is paid on a percentage of the revenue or fare level. Then the financial revenue to the operator increases $h_f$ would move towards $h_e$ and at a particular value $h_f$ would coincide with $h_e$.

**Strategy II**

By removing taxes on inputs to bus operations and/or by providing subsidies to reduce the financial cost to the operator also a conjoint optimality can be reached. This strategy could be applied in two sequential steps.

**Step 1:** In some cases the removal of taxes on inputs to bus operating cost would reduce the financial operating cost; hence $h_f$ would coincide with $h_e$ as depicted in Figure 7. If the percentage of tax concessions is $\Delta g$, then,

$$
FCO'' = (1 + \Delta g/100) * FCO
FCO'' < FCO
$$

**Step 2:** Sometimes removal of taxes alone would not be enough to reduce the gap. In such a cases, the provision of subsidies on a per km or per trip basis would have to be given in addition to or instead of removal of taxes. This we shall refer to as an operating subsidy as it is based on a percentage of operating costs. This too would bring financially viable headway $h_f$ to economic headway $h_e$.

*Figure 7. Effects Of Tax Removal*

*FCO" – Reduced Financial Cost to Operator*
CONCLUSIONS

Many of the past studies related to bus dispatching have not considered the economic cost of standing of passengers. In countries like Sri Lanka passengers regularly travel standing. In this study the economic cost of passengers due to waiting and economic cost of loss of comfort due to standing, economic cost to operator is considered in order to determine the economically optimum headway for a bus route.

The financially viable headway for a route is shown in this paper to be always higher than the economic headway. Optimum headway for a route would be the headway that coincides with both these headways. There are two strategies that could be applied to ensure that a simultaneous optimum for financial and an economic costs are arrived for a single optimum headway for a bus route.

Increasing the financial revenue of operator is one such strategy. This could be achieved by two different methods. One method is to introduce a fare increase, which would increase the financial revenue to operator. Sometimes this method may not be applied due to political or for other reasons. In such situations the second method could be applied, in which some percentage based on the revenue collected by the operators could be provided as a fare subsidy to the operator by the government.

In the next strategy, the removal of taxes on input costs to the operator reduces the financial cost to the operator. If this removal of taxes is not enough to coincide the financially viable headway \(h_f\) with economically viable headway \(h_e\), an operating subsidy based on a percentage of operating costs (per km) could be given by the government until these two headways coincide.

REFERENCES

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This paper discusses two methods to achieve this. One method is to increase financial revenue to the operator by increasing fares or by providing some percentage of revenue to operator by the government. Second method is to remove taxes on inputs to bus operation or to provide subsidies to operator to reduce financial cost to the operator. Using these two methods conjoint optimality could be reached.

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If we examine closely the currently practiced method of dispatching buses in Sri Lanka, it is based on maximizing the revenue for the service provider often at the expense of the quality
of the service anticipated by the passenger. That is the bus is loaded to maximize the revenue to the operator at the expense of increasing waiting time and discomfort to the passenger. In many cases this leads to negative effects to the country’s economy such as loss of time and fatigue of the passenger that leads to lower productivity and economic activity.

The studies mentioned above have another deficiency in application to Sri Lanka that is they have assumed that every passenger is seated. But in a country like Sri Lanka, this is not the case. Many passengers travel standing and therefore when dispatching buses, the economic cost of discomfort (increased fatigue) due to standing must also be considered (Kumarage et al, 2001). Therefore the past studies on bus dispatching can not be directly applied in Sri Lanka.

In this paper an attempt has been made to include the economic cost of standing as well as to relate both the financial and economic cost considerations in the provision of bus services on a particular route.

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In calculating the economic cost to the passengers, following assumptions were made. The entire traffic day on an entire route and for simplicity in analysis, a route where all passengers board at the starting terminal and alight at end terminal – that is there are no intermediate stops. Then we observe that the number of passengers standing in a bus can be found from the relationship

\[
\left( D - \frac{C}{h} t_d \right) \quad \ldots (1)
\]

where,

- \( h \) – average headway
- \( D \) – average demand of boarding per route per day
- \( C \) – average seats per bus and
- \( t_d \) – length of traffic day.

The headway at which passenger would begin to start to travel standing if identified as \( h_0 \) can be calculated as
\[ h_0 = \frac{C}{D} t_d \quad \ldots \ldots (2) \]

Assuming passengers arrive at the boarding terminal at uniform rate with respect to time, the variation of economic cost to passenger could be mathematically expressed as

\[
\begin{align*}
\text{Economic Cost to Passengers} = \text{ECP} &= \begin{cases} 
  h < h_0 & = \frac{1}{2} \gamma_c D \\
  h > h_0 & = \frac{1}{2} \gamma_c D + \left( D - \frac{C}{h} t_d \right) \gamma_s
\end{cases} \quad \ldots \ldots (3)
\end{align*}
\]

Where,
\[ \gamma_c \] – average cost of waiting per passenger per unit time
\[ \gamma_s \] – average cost of standing per passenger per unit time and
\[ t_t \] – average time per trip from terminal to terminal.

This variation in economic cost to passengers is depicted in Figure 1.

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**Operating Cost of Buses in a Route for a Day**

The financial cost to all the operators of buses on a route for a traffic day can be given by the equation

\[ \text{Financial Cost to Operators} = (FCO) = \left( \frac{t_d}{h} \right) \epsilon_f \quad \ldots \ldots (4) \]
Where \( C_f \) is the financial cost of operating a single trip from one terminal to another. The corresponding economic cost of bus operations to the country can be given by the equation

\[
\text{Economic Cost of Operation } = (ECO) = k_{sp} \left( \frac{t_d}{h} \right) C_f \quad \ldots \ldots \quad (5)
\]

where \( k_{sp} \) is the shadow price factor on economic inputs when they are taxed \( k_{sp} < 1 \) and when they are subsidized by the government \( k_{sp} > 1 \). When this equation is closely analyzed it can be observed that the economic cost of bus operations would decrease exponentially with headway and increase linearly with increasing trip time. This is shown in Figure 2.

**Figure 2. Economic Cost To Operator For A Route For A Day**

\[ \text{ECO} \quad \text{– Economic Cost to Operator} \]

**DISPATCHING ON ECONOMIC CRITERIA ONLY**

If the total economic cost of the route, to the country is given by the equation

\[
f_{tec} = f_{ecw} + f_{eco} \quad \ldots \ldots \quad (6)
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where the economic cost to the passengers and economic cost of bus operations are represented by the functions \( f_{ecw} \) and \( f_{eco} \). The total economic cost is shown in Figure 3. As shown in most past studies such as Newell’s Dispatching Policy (Newell, 1971) the most
economic dispatching headway would be the headway that has the minimum total economic cost. This is given as \( h_e \) when headway is

\[
\frac{d(f_{ec})}{dh} = 0 \quad \text{or} \quad \frac{d(f_{ec} + f_{eco})}{dh} = 0
\]

Cost (Rs. / Day)

DISPATCHING ON FINANCIAL CRITERIA ONLY

We can similarly construct the basis on which financially derived headway is arrived at. This can be done by calculating the total financial cost and the financial revenue to the operator, of operating the route over a traffic day.

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Where,

- **ECP** – *Economic Cost to Passengers (Waiting and Standing Costs)*
- **ECO** – *Economic Cost of Bus Operations*
- **TEC** – *Total Economic Cost*

**Figure 3. Economic Bus Dispatching**
It can be seen that the financial revenue to the operator is independent of the headway, as it is fixed on a route. The constant $k_t$ depends on the type of a route. For a terminal to terminal non-stop operation as assumed in this analysis $k_t = 1$ and for other routes where passengers alight at intermediate stops $k_t < 1$. Variation in financial revenue to operators, is therefore a horizontal straight line as it is independent of headway, as shown in Figure 4.

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**DISPATCHING ON ECONOMIC AND FINANCIAL CRITERIA**

Figure 5 shows the superimposed costs –economic and financial.

If our objective it to ensure that the dispatching rate can achieve both economic and financial optimization of costs simultaneously then we need to have a joint optimality condition where $h_e$ and $h_f$ coincide or at least are as close as possible to each other. Two different strategies can be shown to achieve this.
Strategy I

Increasing the amount of financial revenue to the operators is the first strategy. Two methods could be applied for this strategy. One is to increase the unit fare paid by the passenger and the other is to provide some percentage of financial revenue to the operator by the government as a subsidy.

**Method A:** The first method is to increase the bus fare by percentage $\Delta f$, whereby total revenue is increased to match the cost so that $h_e = h_f$. Therefore,

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$$FRO' > FRO$$

Due to the elasticity in demand, when fares are increased revenue would be slightly less than the above calculated value. Effects of this are shown in Figure 6.

**Figure 5. Financial And Economic Bus Dispatching**

**Figure 6. Effects Of Revenue Increase**
**Method B:** The second method could be applied when fare increases is not a viable solution due to affordability, or other reasons. This is by providing some percentage of financial revenue or subsidy to the operator by the government so that the revenue to the operator is increased. This we shall refer to as a fare subsidy as the subsidy is paid on a percentage of the revenue or fare level. Then the financial revenue to the operator increases \( h_f \) would move towards \( h_e \) and at a particular value \( h_f \) would coincide with \( h_e \).

**Strategy II**

By removing taxes on inputs to bus operations and/or by providing subsidies to reduce the financial cost to the operator also a conjoint optimality can be reached. This strategy could be applied in two sequential steps.

**Step 1:** In some cases the removal of taxes on inputs to bus operating cost would reduce the financial operating cost; hence \( h_f \) would coincide with \( h_e \) as depicted in Figure 7. If the percentage of tax concessions is \( \Delta g \), then,

\[
FCO'' = (1 + \frac{\Delta g}{100}) \times FCO
\]

\( FCO'' < FCO \)

**Step 2:** Sometimes removal of taxes alone would not be enough to reduce the gap. In such a cases, the provision of subsidies on a per km or per trip basis would have to be given in addition to or instead of removal of taxes. This we shall refer to as an operating subsidy as it is based on a percentage of operating costs. This too would bring financially viable headway \( h_f \) to economic headway \( h_e \).

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CONCLUSIONS

Many of the past studies related to bus dispatching have not considered the economic cost of standing of passengers. In countries like Sri Lanka passengers regularly travel standing. In this study the economic cost of passengers due to waiting and economic cost of loss of comfort due to standing, economic cost to operator is considered in order to determine the economically optimum headway for a bus route.

The financially viable headway for a route is shown in this paper to be always higher than the economic headway. Optimum headway for a route would be the headway that coincides with both these headways. There are two strategies that could be applied to ensure that a simultaneous optimum for financial and an economic costs are arrived for a single optimum headway for a bus route.

Increasing the financial revenue of operator is one such strategy. This could be achieved by two different methods. One method is to introduce a fare increase, which would increase the financial revenue to operator. Sometimes this method may not be applied due to political or for other reasons. In such situations the second method could be applied, in which some percentage based on the revenue collected by the operators could be provided as a fare subsidy to the operator by the government.

In the next strategy, the removal of taxes on input costs to the operator reduces the financial cost to the operator. If this removal of taxes is not enough to coincide the financially viable headway \( h_f \) with economically viable headway \( h_e \), an operating subsidy based on a percentage of operating costs (per km) could be given by the government until these two headways coincide.

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