SYSTEM COST ESTIMATION FOR AN URBAN MULTI-MODAL TRANSPORT CORRIDOR

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ABSTRACT

Transport projects are mostly evaluated on the basis of the impact on the specific network for that mode and not on the wider multi modal transport network such a mode may be a part of. Previous research derives a mathematical expression for estimating the system cost of a multi modal transport corridor based on cost of vehicle use and user time summed across each motorized mode of transport servicing that corridor. This paper develops the estimation of transport system cost to include (i) external costs due to congestion, emission and accidents (ii) infrastructure cost and (iii) non-motorised user costs including that of pedestrians. System Cost often referred to as Social Cost in transport project evaluation, includes costs pertaining to the provision, operation and maintenance of the transport system as well as external cost of any impacts on third party or non users. The inclusion of these components would complete the representation of most, if not all quantifiable components in the cost estimation of a multi modal transport corridor. The application of the systems methodology in computing total system cost is illustrated using a 20 km section of the Colombo-Galle multi modal corridor in Sri Lanka.

Keywords: multi modal transport corridor; transport system cost; external cost; infrastructure cost; non-motorized user cost

1. INTRODUCTION

The system cost of a transport network is defined as the cost induced by all transport operations impacting all users of the network as well as the non-users among its stakeholder society. This cost is also referred to as the economic or social cost of transport and is often classified further as internal and external costs (Baum, et al., 2008). Internal costs are those costs which are directly borne by the user and external costs are those which are induced by the users of the system but are passed on to third parties and the general public.

The treatment of infrastructure costs arising from the cost of restoration, operation and maintenance of road, railway terminals, stations and parking facility etc for which direct payment is not made by the user, is usually not accommodated within these two cost components. Therefore infrastructure cost is proposed as a third component to be added alongside the internal cost and external cost in estimating total system cost in order to improve the accuracy of estimating total system cost.

However the simple aggregation of these three cost components will not yield an accurate total system cost either, as some of them are not mutually exclusive. For example, though fuel cost paid by the user is a part of vehicle use cost and usually considered as an internal cost, a part of such costs namely the tax or subsidy component, as the case may be, would be transferred to a road maintenance fund to meet costs relating to the provision and maintenance of road infrastructure. As such, that cost component which is part of vehicle use cost that makes up the internal cost should be identified and deducted from the infrastructure cost in order to avoid double counting.
The total system cost can be mathematically represented as $A \cup B \cup C$ and further be simplified as

$$A \cup B \cup C = A + B + C - \{A \cap B + A \cap C + B \cap C - 2(A \cap B \cap C)\} \quad (1)$$

However, if cost components are mutually exclusive, then

$$A \cup B \cup C = A + B + C \quad (2)$$

This research paper proposes a methodology to (i) identify mutually inclusive cost components and thereby (ii) avoid double counting of such cost components.

2. COST STRUCTURE

Internal costs include mainly, the vehicle user time cost usually representing the value of total time loss and vehicle use cost representing the value of the vehicle use including costs for fuel, lubricants, tyres, labor, parts for repairs, operator (crew) labor if applicable, depreciation and interest, and overheads such as insurance, license and administration fees. External costs on the other hand arise only from the user behavior and primarily include congestion, accident and emission costs. In relation to the definition of system cost, the infrastructure cost introduced in this paper includes cost of restoration, operation and maintenance of the fixed infrastructure.

As demonstrated by Hjelle (2003); Maibach, et al.(2008) and Stefan, et al.(2010) the conventional approach in determining road user charges is to assume that all external and infrastructure cost components are fully internalized and recovered through taxation processes based on the principle of ‘user- pays’. In practice it is observed that vehicle use cost include various tax components to compensate these impact made by users upon the physical fixed infrastructure as well as the external environment. Thus the crucial factor in estimating total system cost is the identification of (i) these overlapping cost elements, (ii) the degree to which such costs are internalized and (iii) any balances that may not be internalized. For further analysis, this situation can be illustrated under two possible scenarios;

_Case 1-Full Internalization:_ Where all the external costs and infrastructure costs are fully internalized to vehicle use costs. This would mean that the total system cost would be equal to the internal cost which is the aggregation vehicle use cost and user time cost.
**Case 2: Partial Internalization:** Where only a part of the external and infrastructure costs are internalized to the vehicle use cost. Thus the total system cost would be obtained by adding up to the internal cost that part of the external and infrastructure costs which is not internalized. This is illustrated in Figure 2.

![Figure 2. Illustration of Inter-relationships among Cost Components](image)

Partial internalization without adjustment however, leads to double counting. Hence the adjustment required is to (a) drop tax components included in vehicle use costs and (b) estimate total cost for respective external and infrastructure cost elements to be without subsidies.

For example, part of accident costs may be incorporate to the vehicle use cost in terms of payments made as insurance premium. Hence the insurance payment will be (a) dropped from the calculation of the internal costs but (b) included as accident costs to the society under external costs. The external cost if higher than the direct cost of insurance premium paid would mean that society at large is subsidizing the user, while a higher recovery than the actual cost would mean that a surplus is paid by the users as taxes to society at large. Similarly, infrastructure cost can be adjusted by dropping the component in fuel prices levied as a road maintenance tax and by simultaneously considering the full agency cost of providing the infrastructure for public use. In general, extension of this approach will eliminate the double counting, thus enabling the accurate estimation of total system costs. Figure 3 illustrates the treatment of cost elements by isolating them after removing the double counting so that the infrastructure cost is fully represented by the restoration, operation and maintenance costs and whereas the external costs are represented by the emission cost and accident cost.

![Figure 3. Isolated Cost Elements](image)

Once the cost elements are isolated, the total system cost can be obtained by the simple aggregation of the three cost components represented mathematically as given in Equation 2. While this paper
identifies only the most important cost elements for the purpose of illustrating the proposed costing methodology, there may be other external and infrastructure cost elements that would also need to be treated by this methodology depending on the application context.

3. EVALUATION OF SYSTEM COST

Previous research (Kumarage & Weerawardana, 2013) proposes a methodology for assessing and selecting the most appropriate transport solution in an urban transport corridor by considering a Multi Criterion Analysis approach taking economic, social and environmental criteria into account. This is done by formulating a set of equations for estimating vehicle use cost, user time cost, emission cost and congestion cost. Although these cost elements are identified and estimated individually, they are not adjusted to eliminate overlapping costs. Hence this research paper will suitably modify these equations as follows to obtain an accurate total system cost based on the discussion in the previous section. Further this paper introduces new equations for estimating accident cost and infrastructure cost for a transport corridor.

3.1 Internal cost

Kumarage & Weerawardana (2013) gives total internal cost (TIC) for a multi modal corridor representing the vehicle use cost and user time cost on a single link k aggregated across all links l by each mode j across all modes m and for a single user i aggregated across all users n. The total internal cost for a given period t (TICt) is expressed as follows;

\[
TIC_t = \sum_{k=1}^{l} \sum_{m=1}^{n} \sum_{i=1}^{a} \left( P_{i,j,k,t} C_i T_{i,j,k,t} + L_{i,j,k,t} C_i T_{i,j,k,t} \right) + \sum_{j=1}^{m} \sum_{k=1}^{l} \left( V_{j,k,t} O_{j,k,t} D_{j,k} \right)
\]

where \( P_{i,j,k,t} \) is the flow of user type i on link k on mode j during time period t, \( L_{i,j,k,t} \) the flow of freight type i on link k on mode j during time period t, \( T_{i,j,k,t} \) the average travel time for user type i on link k on mode j during time period t, \( C_i \) the unit value of time for passenger type i and the \( C'_{i} \) unit value of time for freight type i, \( D_{j,k} \) the travel distance of vehicle type j on link k, \( V_{j,k,t} \) the flow of vehicle type j on link k during time period t and \( O_{j,k,t} \) the cost for vehicle type j to operate a unit length on link k during time period t. Modes covers both road and rail whereas vehicle type include non-motorized transport such as pedestrians and cycles.

Out of two cost components in equation 3, vehicle use cost includes taxes levied with respect to covering either fully or in part the external and infrastructure cost elements. For the purpose of eliminating such cost elements \( O_{j,k,t} \) has to be estimated neglecting all such taxes in determination of isolated vehicle use cost.

3.2 External cost

External costs generated through transport operations and imposed on the society primarily include congestion cost, accident cost, emission cost, noise cost, costs borne through water and soil pollutions etc. As the magnitude and the degree of penetration of these external effects are hardly quantifiable, precise cost estimation is difficult. However, most countries adopted approximate and often different methodologies to evaluate these external effects. In keeping with the focus of this paper only congestion cost, accident cost and emission cost will be considered as external costs for the purpose of illustrating the proposed approach.
Congestion cost is calculated in terms of incremental user time and the use cost. Most economists would assume that congestion cost is included in the internal cost as it is a cost imparted on users themselves (Cerwenda & Ruhle, 2009) and its consequences transferred only minimally to the non-users in terms of air and noise pollution. Equation 1 calculates user time cost based on average travel speeds thus assuming the presence of both the congested and uncongested flow condition prevailing on that road or rail corridor. Thus the methodology directly internalizes congestion cost without differentiation time spent in congested or uncongested travel conditions.

Similar to congestion, accident cost is also imparted on users but restricted to identifiable individual victims whereas congestion cost is spread over all user of the road section being considered (Maibach, et al., 2008). Hence accident costs are more a personal cost that should be evaluated separately using Equation 4 which follows the same link based analogy of Equation 1. Since we have already eliminated the insurance cost from the vehicle use cost estimate in Equation 1, the total accident cost (TAC) is derived in Equation 4.

$$\text{TAC}_t = \sum_{k=1}^{l} \sum_{j=1}^{m} \left( V_{j,k,t} D_{j,k} A_j \right)$$

(4)

where $V_{j,k,t}$ is the flow of vehicle type $j$ on link $k$ during time period $t$, $D_{j,k}$ the distance travelled by vehicle type $j$ in link $k$, $A_j$ the estimated accident cost per vehicle km of vehicle type $j$; calculated based on national accident data.

Emission cost in contrast to both congestion and accident costs affects both the user and non-user groups in the society. Emission levels and costs are usually related to fuel consumption based on vehicle type, load and operating speed (Feng, et al., 2011), Kumarage & Weerawardana (2013) compute the total emission cost for a time period $t$ (TVC$_t$) on a multi modal corridor composed of links $l$ and modes $m$ as follows

$$\text{TVC}_t = \sum_{k=1}^{l} \sum_{j=1}^{m} \left( V_{j,k,t} F_{j,k} E_{j,k} D_{j,k} \right)$$

(5)

where $V_{j,k,t}$ is the flow of vehicle type $j$ on link $k$ during time period $t$, $F_{j,k}$ the fuel consumed per unit distance travelled by vehicle type $j$ at on link $k$, $D_{j,k}$ the distance travelled by vehicle type $j$ in link $k$, $E_{j,k}$ the estimated value of emission cost per litre of fuel for vehicle type $j$ in link $k$ ; selected based on average link speed.

Since we have eliminated the taxes related to emission cost from internal cost estimates in Equation 1, total emission cost (TVC) estimated at its adjusted value can be used for total system cost calculation. Equations derived above for external cost calculations can be used for both road and rail transport. Now total external cost (TEC) would be the addition of emission cost (TVC) and accident cost (TAC)

$$\text{TEC}_t = \text{TAC}_t + \text{TVC}_t$$

(6)

### 3.3 Infrastructure cost

Infrastructure cost can be identified as (i) restoration (ii) operation and maintenance cost in relation to system cost definition. Restoration cost refers to the cost incurred in periodic restoration of capacity whereas operation and maintenance cost stands for routing and emergency interventions. Both these cost elements are variable with use. The cost for restoration, operation and maintenance can be represented for time period $t$ (TMC$_t$) for a multi modal corridor composed of links $l$ and modes $m$ as follows
\[ TMC_t = \sum_{j=1}^{J} \sum_{k=1}^{K} (V_{j,k,t} D_{j,k} M) \]  

(7)

where \( V_{j,k,t} \) is the flow of vehicle type \( j \) on link \( k \) during time period \( t \), \( D_{j,k} \) the distance travelled by vehicle type \( j \) in link \( k \), \( M \) the estimated cost for restoration, operation and maintenance per vehicle km; calculated based on national road sector expenditure data.

Since taxes relating to the cost of restoration, operation and maintenance have been eliminated from internal cost estimates in Equation 1, the total infrastructure cost to be used in the total system cost can be equated to the total adjusted TMC estimated in Equation 7.

3.4 Total system cost

The Total System Cost (TSC) defined as the total cost induced by all transport operations in a network can be considered as the aggregation of internal cost, external cost and infrastructure cost once their mutual inclusivity is eliminated as indicated in equation 3. As such the total system cost for a multimodal corridor can be represented for a period of time \( t \) as the summation of equation (3), (6) and (7)

\[ TSC_t = TIC_t + TEC_t + TMC_t \]  

(8)

where \( TSC_t \) is the system cost for the corridor during time \( t \), \( TIC_t \) the total internal cost (excluding taxes levied with respect to covering either fully or in part the external and infrastructure cost elements) for the corridor during time \( t \), \( TEC_t \) the total external cost for the corridor during time \( t \), \( TMC_t \) the total infrastructure cost for the corridor during time period \( t \).

4. APPLICATION

The use of the above methodology is illustrated using a case study of a 20 km section of the Colombo-Galle Corridor (CGC) between Moratuwa, a suburb and Colombo, the commercial centre of Sri Lanka. The CGC is made up of a six lane road and double track railway illustrated in Figure 4, represented using 8 individual links separated by town centres that have major road intersections and railway stations namely Katubedda, Mt. Lavinia, Wellawatta, Bambalapitiya, Kollupitiya and Lake House as intermediate nodes.

Traffic flow, vehicle mix, passenger flows, speeds and occupancy levels required for input in Equations 3, 4, 5 and 7 obtained from recent studies (University of Moratuwa, 2012) are summarized in Table 1 and Figure 4 are given as daily averages and totals.

<table>
<thead>
<tr>
<th>Pax. Flow, ( P_{i,t} )</th>
<th>32,500</th>
<th>35,000</th>
<th>45,000</th>
<th>57,500</th>
<th>57,500</th>
<th>75,000</th>
<th>92,000</th>
<th>92,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{i,t} ) (min.)</td>
<td>4.1</td>
<td>10.4</td>
<td>8.2</td>
<td>2.8</td>
<td>4.0</td>
<td>3.8</td>
<td>4.6</td>
<td>2.4</td>
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</table>

<table>
<thead>
<tr>
<th>Rail</th>
<th>Moratuwa</th>
<th>Katubedda</th>
<th>Mt. Lavinia</th>
<th>Wellawatta</th>
<th>Wellawatta</th>
<th>Bambalapitiya</th>
<th>Kollupitiya</th>
<th>Lake House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link 1 (2.1 km)</td>
<td></td>
<td></td>
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<tr>
<td>Link 2 (5.2 km)</td>
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<tr>
<td>Link 3 (4.1 km)</td>
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<td>Link 4 (1.4 km)</td>
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<td>Link 5 (2.0 km)</td>
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<td>Link 6 (1.9 km)</td>
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<td>Link 7 (2.3 km)</td>
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<tr>
<td>Link 8 (1.2 km)</td>
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<table>
<thead>
<tr>
<th>Road</th>
<th>Veh. Flow, ( V_{i,r} )</th>
<th>59,210</th>
<th>61,800</th>
<th>62,200</th>
<th>49,500</th>
<th>31,310</th>
<th>51,320</th>
<th>44,320</th>
<th>85,800</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{i,r} ) (min.)</td>
<td>4.6</td>
<td>8.5</td>
<td>22.0</td>
<td>3.4</td>
<td>4.6</td>
<td>9.8</td>
<td>5.7</td>
<td>2.0</td>
<td></td>
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</table>

Figure 4. Transport Characteristics on Colombo-Galle Corridor
Table 1. Traffic Mix and Vehicle Occupancy on CGC by Vehicle Type

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<tbody>
<tr>
<td>Composition (%)</td>
<td>20.4</td>
<td>22.5</td>
<td>13.1</td>
<td>33.6</td>
<td>4.3</td>
<td>1.8</td>
<td>3.4</td>
<td>0.6</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>Avg. Loading (Pax.)</td>
<td>1.4</td>
<td>2.0</td>
<td>4.0</td>
<td>2.0</td>
<td>40.0</td>
<td>1.5</td>
<td>1.5</td>
<td>1.2</td>
<td>1.2</td>
<td>850</td>
</tr>
<tr>
<td>Avg. Loading (Tonnes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>7.5</td>
<td>13.0</td>
<td>28.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Kumarage & Weerawardana (2013) using the same corridor and traffic data estimates internal cost (inclusive of taxes) as USD 214.6 mn per year and emission cost (exclusive of taxes) as USD 0.27 per year. The emission cost however is used in this context without adjustment since there is no environmental levy on vehicle use. The rest of the cost components including accident cost and cost for restoration, operation and maintenance interventions are calculated using Equations 4 and 7 respectively. Table 3 shows the summary of the estimation.

Table 2. Annual Value of Economic Cost Components (2012)

<table>
<thead>
<tr>
<th>Type</th>
<th>Component</th>
<th>Cost (USD, Mn./Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal cost (TIC)</td>
<td>User Time Cost</td>
<td>104.6</td>
</tr>
<tr>
<td></td>
<td>Vehicle Use Cost (excluding taxes)</td>
<td>105.6</td>
</tr>
<tr>
<td>External Cost (TEC)</td>
<td>Emission Cost</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Accident Cost</td>
<td>4.8</td>
</tr>
<tr>
<td>Infrastructure Cost (TMC)</td>
<td>Cost for Restoration, Operation &amp; Maintenance</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>Total System Cost (TSC)</td>
<td>223.6</td>
</tr>
</tbody>
</table>

The revised total system cost is estimated at USD. 223.6 Mn. an increase of USD 9.0 Mn. compared to the Kumarage & Weerawardena (2013). From this example it can be seen that in the CGC, the internal costs are 94.0 %, while external costs are 2.3% and infrastructure costs 3.7%.

Road vehicle use cost is estimated using the HDM 4 program (World Road Association, 2010) calibrated for Sri Lanka. Values of time are taken from published sources (NPD, 2001) and emission costs from (NBRO, 1998) adjusted to 2012 prices. Costs given in Sri Lanka Rupees (LKR) are converted to USD at LKR 130 per 1 USD.

5. CONCLUSION

The paper proposes a methodology for estimating total system cost for a multi-modal transport corridor classified under internal cost, external cost and infrastructure cost. Since these three components are not mutually exclusive, aggregation of them would not provide the correct total system cost. Hence the conventional internalization process currently being used are improved by an approach by which cost components are disaggregated and there after aggregated under the three cost components namely (i) internal, (ii) external and (iii) infrastructure costs, a process wherein, the cost components that are included in two or more components are excludes.

The paper illustrates the computation of the total system cost of a 20 km road and railway corridor section. It shows that this cost calculations can be undertaken with minimum data resources and can be used even in preliminary stage of project selection for transport network improvement. Further the cost calculation can be used as inputs in comparing different project alternative across different modes. System wide analysis across different corridors can also be considered by assuming network cost to be composed by a number of radial and orbital corridors. There is a scope for further research to refine the external cost and infrastructure cost components especially in terms of in the treatment of sunk cost.
REFERENCES


