INFLUENCES OF OPERATIONAL ISSUES ON THE OPERATIONAL COST OF BRT BUSES AND BRT SYSTEMS

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ABSTRACT

Operating costs of city buses have been studied and compared – both between vehicle brands and against other systems like Light Rail and Metro – for decades. "Bus Rapid Transit" systems (BRT), which are currently emerging in many cities worldwide, create new operational-cost questions that are extremely important for local bus operators as well as for the public administrations that co-ordinate system planning and tendering-out of practical operations.

Effective operation-costs of BRT-buses depend on many external socio-economic and geographic factors as well as on technical parameters set by vehicle manufacturers and the maintenance regime. Many of these interact strongly, creating linear, progressive or contrarious dependencies on the total operational cost.

For example, speeding-up of bus-operation on BRT lines by separate lanes etc. will decrease the number of vehicles (and drivers) required, reducing total-system cost. Cost-per-vehicle will increase however, due to higher maintenance efforts and heavier fuel-consumption. Door-layout or seating-arrangement on vehicles will influence station-stopping-times and therefore impact system speed, but also generate investment / maintenance cost for vehicles and station platform doors.

A number of example calculations based on real BRT applications will predict expected levels-of-cost for some typical scenarios and will provide a first foresight for local authorities and interested bus-operation companies.

1. INTRODUCTION & PERFORMANCE INDICATORS OF GLOBAL BRT EXAMPLES

The operative costs of city buses are of high interest for several interest groups in the field of urban transport, because of their numerous implications for urban planning, social life and practical industrial business. Any urban transport enterprise interested in earning money by offering transport must precisely calculate its expenses and the potential ticketing income, government subsidies and other sources of revenue.

Any urban or regional authority planning to improve the conditions of living for its local population must know about the estimated cost required for providing public transport in its area of government, because the social implications for the working population from having or not having the opportunity to work at distant places from their homes are so crucial. Any government not knowing about the estimated cost for providing bus services will either miss additional public welfare by not implementing cheap, efficient transport - or will pay excessive subsidies to local bus operators claiming to need them for operating their vehicles.

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And finally, any local or international financing institution like private banks or development-aid funds will need to know about the expected investment and operational costs of public transport services that apply for funding, in order to estimate the economic and social viability of such projects.

Therefore, the operating costs of city buses have been evaluated and compared against operating environments and other systems like Light Rail and Metro – for decades by numerous scientific institutes and international consultants. Unfortunately, many - if not most - of those studies have been used deliberately to provide arguments for pre-determined opinions and intentions instead of providing rational figures for neutral analysis. Many interest-groups have tried to compare apples with oranges in order to promote or to oppose some project in the public discussion. In the European context, the pro’s and con’s of comparing rail services with bus-based operations have been legion, but usually the results of one calculation have been immediately disputed and rejected by the other fraction.

BRT systems worldwide operate under a wide range of circumstances, resulting in quite different system configurations and operational dimensions. A small set of parameters is given here, showing peak passenger performance, operational speed and vehicle productivity (Pax per Bus).

Figure 1 Successful BRT systems in Latin America and Europe: Bogotá and Istanbul

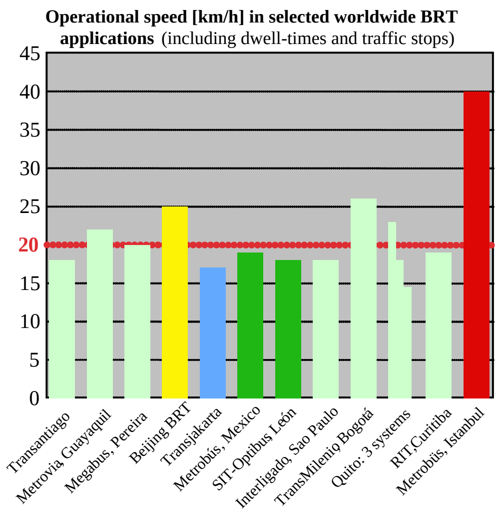

Figure 2 Examples for operational system-speed in BRT systems worldwide

Standard operational speed of most BRT systems is almost 20km/h

Rapid systems (Beijing, Bogotá) operate at approx. 26km/h.

Istanbul BRT is exceptionally fast: 40km/h due to 100% motorway operation, no crossings & traffic-lights.

Necessary vehicle fleet number is direct consequence of operational speed (= required turnaround time). *Speeding-up means significant reduction fleet size &operating cost, and a more attractive PT system!*

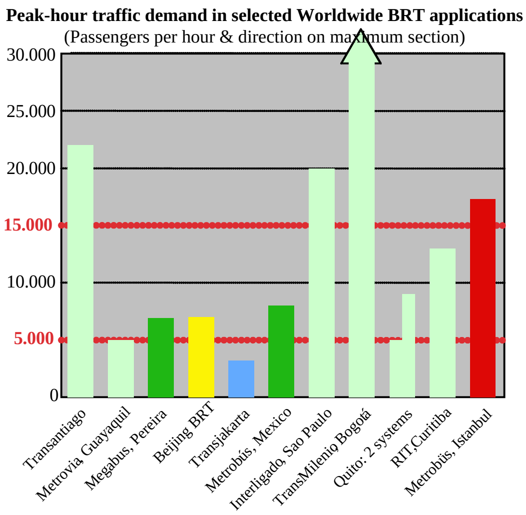

Figure3 Examples for Peak-hour traffic demand in BRT systems worldwide1

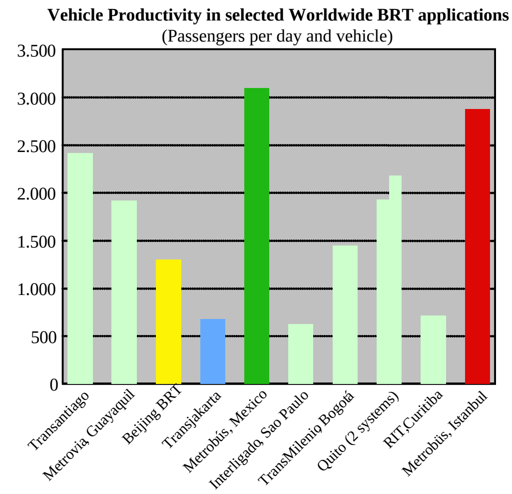

Figure 4 Example indicator "Vehicle Productivity" in BRT systems world-wide

Usual capacity of 5.000 to 15.000 passengers per hour & direction in peak-times

Exceptionally high traffic demand in Bogotá (40.000) is served with double bus lanes, express services and overtaking of stopping buses. This is Heavy Metro capacity level !

Very low capacity in Jakarta because of single rigid 12m buses in operation.

Level of passenger demand is essential for infrastructure investment cost, but has only limited influence on per-passenger operation cost, because vehicle fleet adapts to needs.

Usual vehicle productivity in general urban bus applications is between 250 and 1.000 passengers per bus and day. (Exceptionally efficient ordinary bus systems show values above 2.500.)

BRT applications show strong above-average values of 700 to 3.000 passengers; high figures could indicate dominance of short-distance trips (e.g. Mexico City).

2. GENERAL COST ELEMENTS OF URBAN BUS SYSTEMS AND BRT

In order to develop a common understanding of the total cost for providing bus services, we should first determine the relevant general cost categories:

Investment and Capital Cost always occur when setting up a new system or modernizing an existing operation. Most obvious is the purchase price for new buses, followed by the investment required to establish an appropriate vehicle garage with repair and maintenance facilities and a certain amount of spare parts for immediate availability.

The necessary **investment into Roadside infrastructure** can differ considerably according to the local circumstances and the infrastructures already available on the roads. Frequently, it is being claimed that buses will mostly share their way with the general road traffic, and that they will not require significant investment. But given the vehicle weight and the usual operation frequencies, it is quite obvious that buses are using a considerable

[1] Source: EMBARQ - Preliminary Evaluation of Istanbul BRT, March 2008

share of the local main roads, and that bus stop or terminal facilities have to be erected and paid somehow. This is especially true for modern “Bus Rapid Transit” (BRT) systems, which are focusing on high-capacity, high-speed bus services and which will need significantly more own infrastructures than ordinary commuter buses operating twice or three times a day. Furthermore, specific elements of fixed installations like ticketing facilities, passenger information devices, and possibly full station doors require much construction effort and time. Last, but not least, adequate Administrative facilities are required to maintain efficient operation of any bus service.

This infrastructure related cost (both investment and permanent maintenance) is being omitted here, because it is too dependent on the local situation in terms of climate, topography, spatial structures and aesthetic requirements determined by the general society. Furthermore, it is mostly beyond the influence of a vehicle manufacturer, even if certain interrelations between different vehicle types and infrastructure wear can be assumed. In most bus operation cases - even in famous BRT applications like in Bogotá and Curitiba - these cost is being borne by the local city administration’s roadwork departments, but strictly speaking, it has to be viewed as part of the BRT system cost.

The largest share of the monthly or annual cost of a bus system - especially from a bus operator’ point of view - will of course be the **Direct Operation Cost** with the following major elements:

- Wages for bus drivers, Operational Supervision staff and Administrative staff
- Vehicle fuel and the electricity consumption of garages, stations and administrative facilities. Frequently, lubricants are included here.
- Vehicle Maintenance cost, which consists of garage staff, vehicle spare parts and bus tires. In many modern applications, external contracts have been handed out for maintenance, payable per month and per vehicle-km.
- The continuous operation of bus stops, interchange stations and terminals also causes significant cost, e.g. for the local staff working there, for the maintenance of dynamic passenger information systems. The cost for ticketing systems and procedures has to be covered, containing printing of paper tickets or chipcards, distribution, accounting and collecting the revenues, as well as maintaining ticket machines, and validators / turnstiles. Some modern examples show that it may be more convenient to subcontract the ticketing system as a whole, especially if intermodal ticketing with rail services is being desired or if the physical bus operations have been tendered-out to pure bus-operation companies. *As described above, this cost is NOT being referred here.*
- One other sad cost factor to be mentioned here refers to the cost of vandalism against local installations, which can add up to 4% of the total maintenance cost in some European applications.

Finally, **Indirect Operation costs** will make out some percent of the total operating cost as well. Taxes and insurances have to be paid in order to fulfil local legal requirements and to protect the system. Furthermore, customer communication will be necessary to attract passengers who have not yet been using Public transport. Also, certain overhead costs will occur that have to be covered by the enterprise income.

3. INFLUENCING FACTORS OF BUS-SYSTEM’S OPERATING COST

As described before, each bus operation system in the world heavily relies on **manual work** from bus drivers, maintenance technicians and supervisory staff. Therefore, the local labour wages and working conditions do have massive influence on the total operational costs. Apart from the pure staff wage levels, qualification measures like instruction courses and regular performance checks have to be included. Local specifics in sickness rates and the usual staff fluctuation have to be taken into account.

The second general determining factor is the regional level of **energy prices**. The cost of Diesel fuel is (and has been for decades) the primary source of energy for urban bus operations. Under specific circumstances, the price of natural gas or of ethanol might be relevant. In every case, the electricity price will be very important, because the operations control centre, stationary bus-stop equipment, and the whole garage operation strongly rely upon it.

For the correct transfiguration of one-time investment costs into annual and monthly cost, the **general interest levels, the inflation rate** and the availability of external financing of investment has to be correctly estimated. This includes viable prognoses of such values, as the operative lifetime of buses can be well above 15 years, and fixed installations like garage buildings and terminals can last for more than 50 years.

Specific local and topographic factors do strongly influence the level of operational cost. For example, the local distances between residential, industrial and central urban areas, determine the necessary vehicle mileage. The exact residential population distribution and the number and location of workplaces determine the passenger volumes and their distribution over the day / over the week. The social composition of the population is strongly influencing the modal choice between private car and public transport. Climatic factors like the agglomeration altitude, regional temperatures and the height differences between the stations determine the energy consumption. They also can restrict the economic lifetime of vehicles and infrastructures, if the climate is too hot, too cold or too corrosive for usual materials.

The **general travel patterns**, that are being determined by the topographic and social factors mentioned before, cause major effects on the system performance and the operational cost. Heavy traffic jams, which are reducing the operational speed, will lead to increased requirements in vehicle and bus driver numbers. On the other hand, strong emphasis on express bus services skipping many intermediate stations can both significantly increase the passenger capacity of the bus lanes and improve the system travel speed, greatly reducing the amount of vehicles required against all-stopping services. Furthermore, this operation will reduce the mechanical stress put on the vehicles and will therefore reduce the maintenance effort required for engine, gearbox and driving axle.

Strong **Peak-hour shares i**n total traffic will force to employ large numbers of buses that are only operating few hours per day with very low annual mileages. Also the comfort requirements of customers will determine the number of vehicles to be employed. One example here is the strong desire for transporting mostly seated passengers on the long transport distances common in South Africa, whereas most Latin American systems heavily rely on transporting two thirds of their peak-hour passengers standing, which not only saves required interior space in the vehicle but considerably speeds up the boarding and disembarking process at the major bus terminals.

4. EXAMPLE APPLICATION CASES AND RESULTING LEVELS OF OPERATIONAL COST

In order to illustrate the factors mentioned before, a number of configuration examples will be illustrated and analyzed concerning their operational cost levels. The data originates from a number of sources, partly publicly available and partly from Daimler's internal experience in producing and maintaining urban buses in large transport systems in Latin America. Further input comes from the VOITH Turbo Group that maintains large fleets of automated gearboxes for bus applications in the world and keeps continuous track of their operating environments.

	Latin America	**Europe**	**South Africa**
Traffic data			
Line length	30 km	15 km	30km
Passengers / day	180.000	25.000	100.000
Operative speed	26 km/h	23 km/h	23 km/h
Peak hour share	12%	12%	14%
Vehicle data (18m articulated)			
Seated Passengers	48 seats	48 seats	70 seats
Standees (peak-hours)	112 Pass.	60 Pass.	10 Pass.
Standees (normal hours)	40 Pass.	20 Pass.	5 Pass.
Standees (late hours)	10 Pass.	0 Pass.	0 Pass.
Vehicle lifetime	15 years	10 years	14 years
Fuel consumption	55 l/100 km	52 l /100km	52 l/100km
Driver data			
Annual driver salary	4.800 US$	50.700 US$	12.200 US$
Driver work hours p.a.	1680h	1425h	1200h
Financial data (from Feb. 2008)			
Capital interest rate	8% p.a.	6% p.a.	14.5% p.a.
Diesel fuel price	0,66 US$/l	1,56 US$/l	1,14 US$/l

Figure 5 Examples for input parameters of the calculation model

4.1 Cost Example “Latin American BRT”

This and the following diagrams show the different elements of a “Total cost of ownership” calculation, as described before (and omitting certain infrastructure or ticketing aspects as mentioned). The calculated absolute annual system operation cost (assuming line length, passenger demand, fuel price, wage levels etc.) is put into relation to the vehicle performance and passenger numbers, in order improve the comparison of small and large applications. The figures “Cost per vehicle-km” resp. “Cost per passenger”, also allow direct comparison of the different diagrams in this presentation.

The first example is based on input data from the Bogotá application, but only covers data from one sub-system within the 1.000-buses operations of TransMilenio. It shows a characteristic high operation speed, which enables high passenger performances with relatively few peak-hour vehicles. Passengers use the system not only in the peak-hours for commuting but also during the day, which improves the daily passenger performance of the vehicles employed. This high occupancy also has very favourable influence on the staff efficiency. Furthermore, the price of diesel fuel in Colombia is very moderate, which reduces the energy cost share.

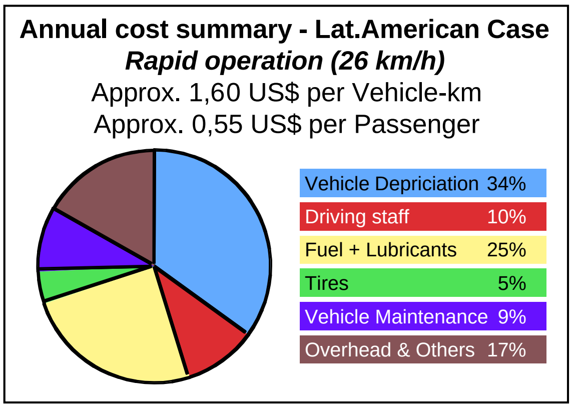

Figure 6 System cost breakdown for "Latin American case, Rapid operation"

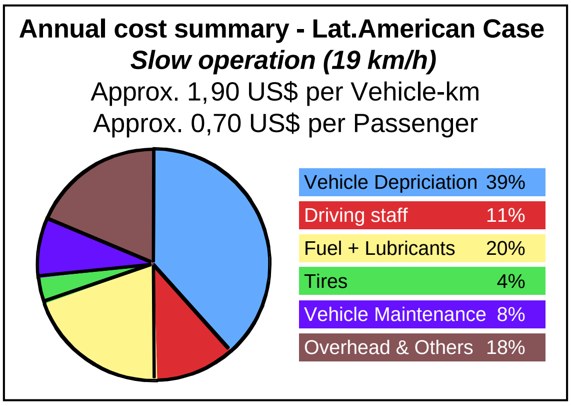

Figure 7 System cost breakdown for "Latin American case, Slow operation"

Vehicle depreciation is the dominating cost element under these conditions, being followed by fuel cost. Driver salaries only account for about 10% of total cost.

A variant calculation with system speeds reduced to the "worldwide common" travel speed for urban buses down to 19 km/h already changes the picture significantly:

The reduced speed would significantly increase the number of vehicles and of bus drivers required, without changing the number of passengers transported. The average cost per vehicle-km and per passenger rises, while the system loses public attractivity.

Another variation of the cost breakdown shows the strong influence of the fuel price on the overall system cost. At an almost European fuel price level, it would become #1 cost factor.

Again, the cost per veh-km and per passenger is rising, but as the number of vehicles remains the same as in the first case due to the high operational speed (26 km/h), the vehicle depreciation cost remains lower.

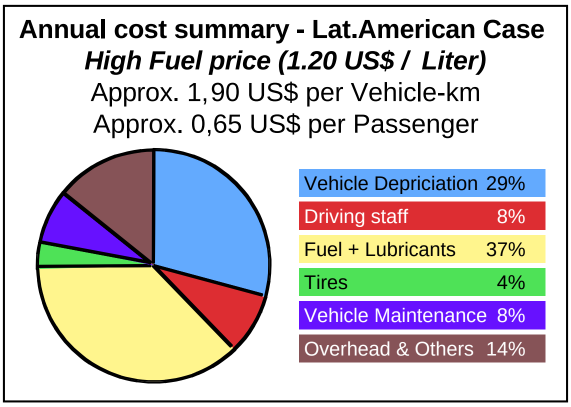

Figure 8 System cost breakdown for "Latin American case, High Fuel price"

This comparison clearly shows the positive impact of speeding-up the urban Public Transport systems. Cost per passenger improves strongly, and the passenger attractivity also rises. Under European conditions, traffic-light priority schemes usually pay off themselves within 2 or 3 years due to the possible savings in vehicle numbers.

4.2 European Application

Using the cost model for a "European" application shows much higher cost per vehicle-km and per passenger, because of much lower absolute passenger volumes and higher comfort requirements (schedule headways calculated with less standing passengers).

The much higher staff salaries usual in Germany and its neighbour countries lift the cost share of wages to approximately half the total cost. Under less efficient operational structures, even 75% wage share have been reported in the past. The absolute level of cost per veh-km reaches almost three times the favourable level of Latin American operations. The cost-per-passenger does not increase in parallel because of the favourable daily distribution of passengers, utilizing the vehicles also in off-peak periods for leisure purposes etc.

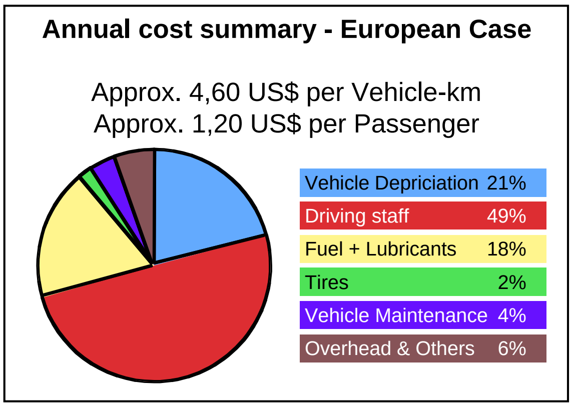

Figure 9 System cost breakdown for "European Case"

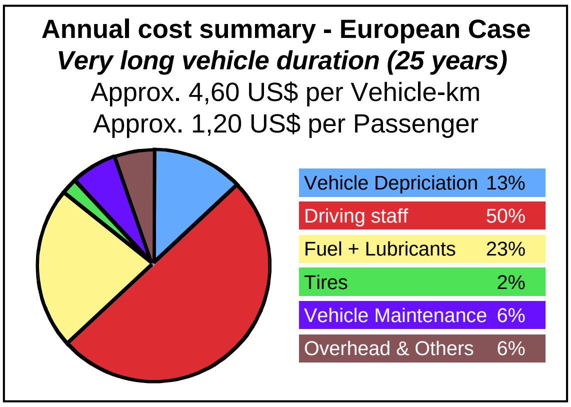

Figure 10 System cost breakdown for "European Case", long vehicle life-time

4.3 Influence of extra-long vehicle lifetimes ("North American policy")

Externally desired factors can significantly determine the operational cost of bus systems. An example for this is a North-American habit of requiring very long economic lifetimes of vehicles up to 25 years. In exchange, the U.S. and Canadian administrations offer strong subsidies for such vehicle purchases (up to 80% of the purchase price). This forces to use extra-heavy vehicle constructions that guarantee such a long vehicle duration, but consume considerable amounts of fuel in accelerating and braking the heavy vehicles.

In consequence, this greatly reduces the annual depreciation needed, but forces the operators to accept much higher fuel consumption and significantly more maintenance and modernization needs for the vehicles. Even with continuous maintenance and modernization in large garages, the technical progress in engine-technology and vehicle-electronics cannot fully be incorporated into vehicles of more than 15 years, denying the operators to generate all available rationalization potentials from state-of-the-art technology, and also denying the regional authorities to benefit from modern ecologic standards and environmental improvements. In terms of "Total cost of ownership" calculation, the balance – which has deteriorated marginally in the example calculated here – will depend on specific local circumstances and figures that are difficult to predict – like staff salaries and fuel prices.

For the mentioned North American operators benefiting from the subsidies, the balance will usually show positive results, as much of the "vehicle depreciation" cost is being taken over by the government.

4.4 First estimation on potential South African Applications

With this synthetic cost model, it is also possible to give a first impression of the expected cost situation of envisaged South African BRT operations. The expected driver salary levels, the cost of fuel and the financial circumstances of vehicle purchase conditions can be assumed in first estimations. Apart from this, it is most important to understand the expected traffic patterns, under which a "South African BRT" might operate.

Here, we have to assume long travel distances from the distant suburbs into the city centre, which require many vehicles because of the long system length. Also, the strong focus on commuting passengers, who concentrate total daily travel demand into few peak-hours, does not leave many passengers during off-peak times for the first operating years. But the most unfavourable aspect will be the high share of seated passengers in the vehicles, which almost doubles the required bus fleet (and driver's numbers) against similar traffic cases in Latin America.

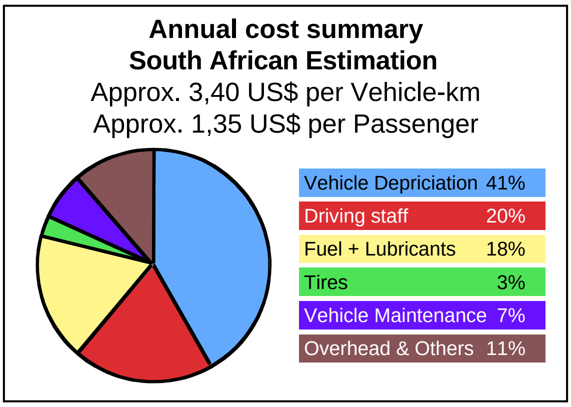

Figure 11 System cost breakdown for "South African Case"

The high share of "vehicle depreciation" results from these unfavourable traffic conditions, which require a large bus fleet without transporting many passengers - neither during rush-hours nor for the rest of the day. Given the same passenger load but only "Latin American" figures of 48 seats and up to 110 standing passengers per articulated bus, the cost per passenger would be reduced to about 0,80 US$, or to 2.90 US$ per veh-km. The share of fuel cost, however, is lower than in Latin America, because of the low fleet utilization (measured in annual km per vehicle), which might reach only half the level of Latin America. The staff cost is higher than in Latin America, because the passengers-per-vehicle ratio is lower at only about 350. The driver's cost share does not reach "European" levels, because the driver's wages are much lower than in Europe.

A second impact shows the possibilities of improving the system economy of BRT operations by attracting off-peak hour passengers. As each BRT system has to be designed for the peak-hour demand, only moderate financial efforts for additional fuel and driving staff are required to serve passengers during mid-day or at late evenings, but significant new opportunities could be created for the less privileged parts of the society by providing them with leisure or education offers inside the city centre.

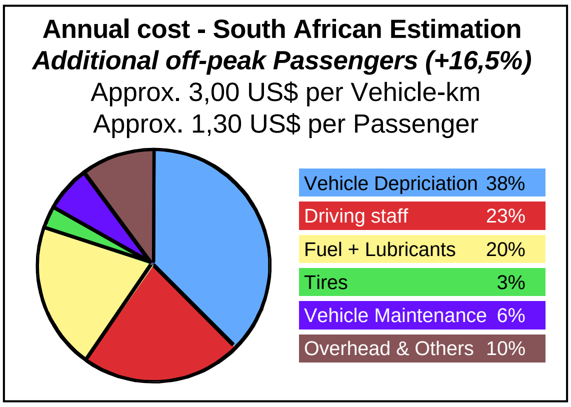

Figure 12 System cost breakdown for "South African case - additional off-peak traffic"

Even if only reduced tariffs-per-passenger might be collected during such periods of the day or for this group-of-passengers, it might well be an overall improvement for the total BRT-system's economy. European experience shows that such an offer will also - on the medium to long term perspective - tend to shift parts of the daily commuting trips towards such times and give a better system utilization, as the last figure shows.

Optimization of the operational conditions as higher speeds and fleet efficiency enables an economic operation of BRT systems in general. Subsidies-free operations imply a high degree of utilization of the system during the whole day to improve the long-term efficiency of South African BRT operations. To ensure this, an alteration in social behaviour is necessary. The extension of opening hours or special offers could be used to promote off-peak travel amongst the population.

It also might be an option to re-calculate the South African applications under the assumption of more doors per vehicle and therefore shorter stopping-times at stations and an increased ratio of standing passengers during peak-hours. This would reduce the number of vehicles needed and therefore reduce the operating cost.

5. RESUMÉ

The indicated examples for operational cost cases clearly show the possibilities of predicting operational cost of BRT systems, based on a handful of economic indicators and traffic determinants. Simple assumptions on the number of passengers to be carried and their average travel distance lead to clear assumptions on the number of vehicles required and their total mileage. Price levels for fuel and operating staff salaries, combined with basic assumptions on vehicle consumption and maintenance needs will give a quick impression on the expected level-of-cost, which again indicates needs for fare levels and subsidy requirements.

It must not be assumed, however, that this model might replace a detailed operational calculation, which takes more variables into account. One example is the seasonal spread of cost indicators, which is being caused by different effects like holiday periods or weather influences. In Bogotá, the maintenance cost per vehicle-km varies more than 20% over the year, depending on the number of vehicles reaching their fixed inspection mileages and the general traffic demand fluctuation.

Given the range of cost results for the different operating environments - we just saw Latin America, Europe and South Africa - the resulting cost estimations showed a wide range between fully profitable operation and strong needs for public support. The local results on each practical case of application can support political debates and decisions by providing first quantitative figures about consequences of different options.

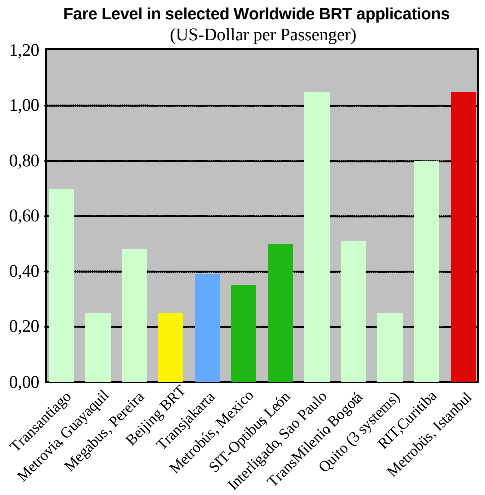

Figure 13 Fare levels in selected worldwide BRT applications

The observed levels-of-tariff show strong differences between the single agglomerations.

Very low tariffs may indicate strong public subsidies, given to support the mobility of less-privileged urban social groups.

Under Latin American circum-stances, fare levels of 0.50 US$ per ticket may be considered profitable without subsidy (Bogotá, Santiago, León, Pereira).

Higher ticket prices (Sao Paulo, Curitiba, Istanbul) may indicate higher fuel cost or higher driver salaries in these cities.

For South Africa, maybe the issue of almost 100% seated-passenger transportation could become interesting, as it will force the operators to provide much more vehicles than for a similar application under American standards. But not only the absolute passenger capacity is influenced by all-seat buses, but also the average system speed at intermediate bus-stops, as it will take significantly longer for passenger exchange, if the number of doors per bus is being limited or if only narrow aisles remain available inside the vehicles. Therefore, very understandable comfort desires have to be weighted against simple economic necessities - that is the resulting ticket price or public subsidy level.

6. SOURCES AND LITERATURE

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