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Competitiveness of trolleybus in urban transport

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Abstract

In the search for alternative transportation modes in urban public transport, this paper suggests a comparison between the competitiveness of trolleybus and diesel bus transport modes. This evaluation is based on the relevant life-cycle costs, highlighting that trolleybus transport has a starting high charge of vehicles and wiring purchase as well as the disadvantage arising, in Italy, from the higher price of electric energy compared with diesel oil. Because of these factors, the trolleybus is less competitive than the diesel bus for the Italian urban centres although more friendly for the environment. In the last part of the paper, a case study shows that energy prices and car purchase have a negative influence on the present competitiveness of the trolleybus.

1 Introduction

After the Second World War, advanced technology and oil low price encouraged the employment of the diesel bus instead of the trolleybus, which was penalised by its overhead contact line that could not meet the requirements of the quick traffic growth in urban centres. Most trolleybus networks were dismantled between the 60's and 70's. Today, the urgent need to reduce air and acoustic pollution in urban areas as well as a greater environmental awareness, also backed by governmental policies, bring about a renewed interest for the trolleybus.

As to the drive development, trolleybus vehicles followed, during the years, the same evolution achieved in the field of light rail EMUs. The traditional traction drive with DC-motors and rheostatic speed regulation by electro-mechanic control of the contactors was replaced first by a solution, still based on DC-motors, but fed by a power chopper for speed electronic regulation, and finally by three-phase AC induction motors fed by an inverter [2]. This solution of the 90's has been applied on all the most updated vehicle types exploiting the power electronics developments, that allow GTO-thyristors employment, and, recently, of IGBT- transistors which simplify circuit layout and performance. The installation of an auxiliary diesel motor is considered vital today because it can assure trolleybus an autonomous running, i.e. without overhead power supply.

The autonomous running simplifies the electrified plants in the depots and assures continuous service also in case of power interruption or in case of unexpected detours. Attracted by the enhanced vehicle performances and by the lower environmental impact of trolleybus, many European cities have purchased new vehicles during the last years; Table 1 shows the most recent 18-m-articulated trolleybuses deliveries of the European industries, while Table 2 summarises 12-m-single car deliveries.

Table 1: The most recent deliveries of articulated trolleybuses by the European industry

Manufacturers	Running	Under delivery	Ordered	Total	Years
Berkhof/Traxis	3 Holland	-	35 Germany	38	1999
AnsaldoBreda	1 Italy	7 France	-	8	1999
MAN/ADTranz/CAM	25 Italy	28 Italy	-	53	1997/99
MAN/Adtranz	10 Austria + 14 Germany	-	-	24	1992/93
Mercedes/ZF	1 Switzerland	-	4 Switzerland	5	1996
NAV/ABB/Hess	22 Switzerland	-	-	22	1993
NAV/ADTranz/Hess	18 Switzerland	-	8 Switzerland	26	1997
NAV/Siemens/Hess	18 Switzerland	-	-	18	1996
Neoplan(MM)	12 Switzerland	-	-	12	1991
Neoplan/MM/Kiepe	1 Switzerland	26 Switzerland	-	27	1999
OAF (MAN)/ADTranz	5 Austria	-	-	5	?
Van Hool/ADTranz	18 Switzerland +8 Holland	-	45 Austria	71	1994/95
Volvo/Kiepe	1 Austria	15 Austria	-	16	1999
Totals	*157*	*76*	*92*	*325*	

Table 2: The most recent deliveries of 12-m- trolleybuses by the European industry

Manufacturers	Running	Under delivery	Ordered	Total	Years
AnsaldoBreda	1 Italy	86 Italy	-	87	1999
MAN/Kiepe	1 France	5 France	-	6	1999
Neoplan/Kiepe	-	96 Greece	-	96	1999
Van Hool/Alstom	-	96 Greece	-	96	1999
Totals	*2*	*283*		*285*	

Though the recent issues encourage trolleybus employment, the high costs of vehicle purchase and the high investments for construction and maintenance represent a great constraint to trolleybus revival [1]

2 Formulation of a comparison between trolleybus and diesel bus

The need for mobility in the metropolitan areas can be met through different transport modes, each offering variable performances and capacities, in terms of passengers/h, within a given interval. Both trolleybus and diesel bus offer equivalent performances and transport capacities, i.e. two viable alternatives to meet the same segment of mobility demand. The choice between these two modes can be made on the base of economic and environmental factors as well as evaluating the possibility to enhance supply according to possible demand rise.

It can be primarly claimed that trolley mode in comparison with the bus causes higher investment to purchase vehicles (the price for one trolleybus is equal to 1.5 - 2 times the price of one diesel bus having the same capacity) as well as for construction and maintenance of the fixed installations; nevertheless, trolleybus has a longer life-cycle in comparison with diesel bus and requires lower maintenance costs.

Consequently, the proper choice between the two modes should be based on the comparison between the two life-cycle costs. As to the energy costs, diesel oil has the same price on the whole Italian territory while power supply costs can be different for the transportation enterprises because of the different contract types. It is important to take into account that even if power supply has on one hand lower costs than diesel oil, it could still be, to some extent, less competitive because diesel oil allows the public enterprises to obtain tax reduction.

Trolleybuses, compared with diesel buses of the same size, show a slightly higher capacity, because part of the electric equipment can be installed on the roof.

An important and peculiar item for trolleybus cost evaluation is represented by electric traction installations made of a overhead contact line, the relevant supports, and the conversion substations. Overhead line cost depends on the chosen solution. For the European installations new generation, the system of the Swiss manufacturer Kummler+Matter is widespread with the estimated cost of 100,000 Euro/km. The costs of the conversion substations, consisting of a small-sized building and one or more units equipped with a transformer, a silicon rectifier and a breaker, depend on the power supply; a 1,500 kW substation can approximately cost about € 300,000.

The cost of a complete trolleybus system can have a great range of variation. The most updated costs (year 2000) for recently achieved trolleybus lines concern two lines of Genoa (Italy), each 3 km long: 12.4 Million Euro for the first line, and 16.5 Million Euro for the second including purchase of new vehicles.

3 Operation costs of trolleybus lines

Trolleybus lines operation includes staff costs, power supply, and maintenance of vehicles and installations.

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Trolleybuses require daily maintenance (checking of trolleys, of leakage detectors, of tyres and general overhauling of vehicle mechanics), weekly maintenance (check of electric insulation, of lubricant level, of door operation devices), and monthly maintenance of storage batteries.

Different sources are available for maintenance cost estimation both for trolleybuses and diesel buses. The Italian Ansaldo has estimated that the average maintenance/repair cost by km for motor buses is higher than 33% of the costs required by dual mode trolleybuses, both 12-m and 18-m-vehicles. According to the estimation of the said manufacturer, the annual costs for fixed installations maintenance amounts to about 0.2 Euro/km. As to the installations, it should be stressed that the electric substations require a few maintenance operations; contact line maintenance charges are higher, whereas wire and equipment wear, in general, are to be prevented.

About the energy consumption of one trolley-bus there are discordant estimations. Route and services modes, which are different for each city, influence consumption. Contracts for power supply drawn up with the transport operators differ from each other. Binomial contracts prevail, i.e. partially proportional to consumption, partially proportional to the contracted power supply. The energy unit cost c in this type of contracts can be assessed by the following formula:

$$c = \frac{\gamma_1 \cdot p}{P} + \gamma_2 \cdot k$$

whereas y_1 is the coefficient of the monthly tariff amount bound to the contracted power, p is the power and P the trolley-bus miles monthly covered, y_2 the coefficient of the monthly tariff amount relevant to the consumption, and k electric power consumption/route unit.

According to the data issued by the Italian transport enterprises, the specific trolleybus consumption ranges from 2 to 4 kWh per covered km; Ansaldo indicates, though, a specific consumption of 1.18 kWh/km for one 12-m trolleybus, which is to be compared with the average miles covered by a diesel bus, i.e. 1.9 km/ liter of diesel oil. Combining specific consumption with electric power tariffs, the result is an average cost for traction energy of 0.15-0.20 Euro/km.

4. Economic evaluation based on life-cycle cost

In this paper no environmental parameters will be taken into account. Trolleybus compared with diesel bus clearly gives higher environmental benefits reducing air and acoustic pollution; however, in absence of reliable economic evaluation of environmental impacts caused by diesel vehicles, they cannot properly be included in the economic comparison of the two modes.

A diesel bus life-cycle is estimated in 13 years in [3] and in an Ansaldo source; other sources mention 14 years. The same sources indicate for trolleybus respectively the life-cycle of 20, 23, and 19 years. The economic troubles of urban public transport operators cause longer life-cycles, i.e. over the reasonable limits. All the sources unanimously indicate that trolleybus life-cycle is longer than diesel bus one of about 50%. It is also important to observe that a diesel bus has, at the end of its life-cycle, a residual value of 5% of the initial one, while a trolleybus shows a residual value of 20% of the initial one. This rate grows for overhead contact line and sub-stations respectively to 30% and 20%.

As service type and electricity tariffs greatly vary, it is very difficult to assess trolleybus competitiveness covering all the urban contingencies; therefore, its application on a case study taken as an example is proposed: the extension of an existing trolleybus line for a new route of 2 km equipped with two double-wired overhead lines and covered by 7 12-m long trolleybuses; fixed installation life-cycle is 30 years. Trolleybus and diesel bus operation will be compared on the same route. This case study is tailored on the peculiarity of the Italian cities.

The major cost items for start-up and operation of the new line for the two options, trolleybus and diesel bus, are listed on Table 3. Data are given by the line section operator, an Italian public transport enterprise; in particular, traction energy unit costs of 0.37 Euro/km for a trolleybus and 0.2 Euro/km for diesel bus have been assumed. Performance, cost for drivers (1.6 Euro/km) and revenues (33,466 Euro/(bus · year) are the same for the two options. This value is obtained multiplying unit revenues on the considered urban network, 3,298 Euro/(bus · km) and distance covered by a bus on the new line section, 5,482 km/year, to be added to the advertising revenues and the funds paid out by the Region.

Table 3: Cost items for the examined case

Cost items	Trolleybus	Diesel bus
Purchase of 7 vehicles	409607×7 Euro	218021×7 Euro
Fixed installations	929621 Euro	-
Traction energy	14199 Euro/Year	7675 Euro/ Year
Maintenance	17269 Euro/ Year	23102 Euro/ Year
Drivers	61401 Euro/ Year	61401 Euro/ Year

With these data, the Updated Net Value (U.N.V.), based on the cash low updating U_k (receipts and payments), can be calculated over a period of $N = 23$ years, corresponding to a trolleybus life-cycle, and with the discount rate i fixed at 2.7%, i.e. the max. rate allowed by the European Central Bank for the Members of the European Monetary System.
From the formula:

$$\text{U.N.V.} = \sum_{k=0}^{N} \frac{U_k}{(1+i)^k}$$

the values summarised on Table 4 have been calculated.

Table 4: Results of U.N.V. calculation

Examined cases	**U.N.V. for one trolleybus**	**U.N.V. for one diesel bus**
Initial data	70914 Euro	- 25450 Euro

In order to obtain the results above, the cost items on Table 3 have been taken into consideration adding, for the option diesel bus, purchase of new vehicles after termination of the first purchased vehicles life-cycle, i.e. in the 13th year, and, for the option trolleybus the vehicles residual value of 92,869 Euro, i.e. in the 23rd year. As to the cost of the fixed installations, the unsecured contribution has been subtracted from the cost as stated by the local transport operator; the result has been divided by the vehicle number.

5 Conclusions

Trolleybus employment in urban transport is more attractive than diesel bus from an environmental point of view, but it is penalised by the high vehicle cost and by electric energy contracts. For the chosen example tailored on the peculiarity of the Italian cities the trolleybus operation has shown higher charges, as life-cycle, for the operators compared to the ones of diesel bus. If the energy price will be reduced for the transport enterprises as a consequence of the market liberalisation or of contributions to reduce urban pollution, the costs for trolleybus operation will balance the ones for diesel bus operation. It is to be remarked that no economic evaluation has been given in our analysis to air and acoustic pollution reduction, which is undoubtedly an added value allowed by trolleybus; quantification of these environmental benefits can be the topic of a further study and will surely swing in favour of trolleybus.

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