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Urban public transport in Europe: Technology diffusion and market organisation

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ABSTRACT

Technological change and incremental technology, at various levels, are believed to have played an important role in the success of urban public transport in Europe. In this paper, a historical overview of the evolution of different transport modes across different European cities is presented. Our major concern is with the processes of diffusion of urban transport modes in European cities and, in particular, with the factors, mainly of an economic nature, that may explain their rates of adoption across Europe. Among these factors, special attention is given to the role played by the dimension and organisation of public transport markets in the rates of adoption of different public transport modes. The main conclusion of the paper is that the success of the introduction of a new transport mode appeared to be mainly related to its ability to provide cheaper and more reliable transport services compared with previous transport modes, and that, in the case of the electric tram, this was achieved by transforming of the structure of the market relating to this urban transport mode into monopolies.

1. Introduction

Technological change and incremental technology, at various levels, are believed to have played an important role in the success of urban public transport in Europe. Up to date, however, the study of both use and disappearance of technology, particularly of that related to the different modes of transport in urban areas, has not been a recurrent topic of research in academia (see Lindqvist (2004), cited in Edgerton, 1998).

In this paper we present a historical overview of the evolution of different transport modes across Europe. By 'public transport' is meant a service transporting passengers along a predetermined itinerary and frequency in exchange of a fare. The discussion is carried out in turn of the modes of public transport widely in place, at some point in time, during the short history of urban public transportation, namely those of the horse omnibus, the tram (horse and electric), the trolleybus, the motor bus and the metro.[1]

Our main concern in this paper is with the processes of diffusion of urban transport modes in European cities and, in particular, with the factors that may explain the rates of adoption of these transport modes, especially those of an economic nature. Among these factors, special attention is given to the role played by the dimension and organisation of transport markets in the rates of adoption of urban transport modes across Europe.

Therefore, the main objective of the paper is to scrutinise the reasons that may explain the paces of diffusion of different urban transport modes in European cities. The methodological approach used to accomplish this objective rests on: (i) the presentation of a set of historical records of the introduction, diffusion and decline of different urban transport modes in

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[1] The train is left outside this analysis because, in many urban areas, it is difficult to distinguish when the services were of suburban or interurban nature.

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Europe, providing, whenever possible, information about the costs and effectiveness of the transport services provided in each case; and (ii) the analysis of the evolution of the structure of public transport markets relating to each urban transport mode, which consisted, in most cases, of three stages – the entrepreneurial stage, the consolidation stage, and the involvement of public authorities in the provision of transport services.

Our main argument is that the success of any new mode of transport appears to be related with ability to drive costs down and provide reliable, comfortable and safe services. Using the case of the electric tram, we show that the success of this urban transport mode, measured by its fast pace of diffusion across Europe, appears to have been related to its ability of providing affordable public transport services, which enabled the increase in the utilisation of urban public transports in Europe. We also show that the introduction of the electric tram only became economically feasible with the transformation of the structure of the market relating to this public transport mode into monopolies. On the other hand, using the cases of the trolleybus, motorbus and underground systems, we show that the slower diffusion of these urban transport modes across Europe appears to be mainly explained by its inability to provide more effective and cost-competitive transport services compared to the electric tram.

The remainder of the paper is organised as follows. Section 2 focuses on the issues of technological change, stressing, firstly, that the meaning of technological change is essentially related with the process of diffusion and, secondly, that even though the diffusion of technology is affected by a multitude of factors, the market characteristics appear to play a crucial role in the rate of adoption of a new technology. Section 3 analyses a set of historical records regarding, on one hand, the succession of transport modes and their substitution processes throughout the history of urban public transportation in Europe and, on the other hand, the evolution of transport markets relating to each urban transport mode. Section 4 carries out a discussion of the factors that may have driven the rates of adoption of urban transport modes in Europe taking into account the historical records presented in previous sections. Finally, Section 5 presents the main conclusions of the paper.

2. The process of technological change

As Scranton (1995) puts it, the "study [of technological change] has devolved from period to field to multiplying concepts, methods, and theories, profoundly undercutting efforts at synthesis, preservation of canonical narratives, or the naive addition of new knowledge to received wisdom" (p. 35). In fact, conceptual fuzziness and conflicting perspectives are to be found in a literature review on history of technological change (Jamison and Hard, 2003). In the following paragraphs an attempt is made to uncover not only some of the narratives surrounding the history of technology, but also the core determinants of technological change.

Much of the literature on history of technology confronts us with competing narratives regarding the nature of technological change. Firstly, there's a strand of the literature which takes technological change as an evolutionary and path-dependent process, with changes driven by 'Darwin-like' processes (Barley, 1998; Garrison, 2000; Vega-Redondo, 1994). In this body of literature, technological change is usually described using biological metaphors such as "mutation, selection, adaptation, life-cycle, [or] survival of the fittest" (Devezas, 2005, p. 1139). Note, for example, that the logistic equation, which is one of the most powerful technological forecast tools, has its origins in the biological realm. In opposition to this proposal, some authors argue that technology evolves through periods of incremental change punctuated by technological breakthroughs or discontinuities. This notion of 'technology revolutions' or, alternatively, of 'evolutionary discontinuities' (Loch and Huberman, 1999; Tushman and Anderson, 1986), 'waves of technology' (Andersen, 1998) and 'technological shifts'[2], has been introduced in the literature "under the rubric of punctuated equilibria[3] (...), radical and incremental innovation (...) and the evocative image of Schumpeter (...) of 'waves of creative destruction'" (Barley, 1998, p. 246). Nevertheless, a question yet to be answered is "When is incremental innovation dominant, and when (if ever) do radical changes in technology appear" (Loch and Huberman, 1999, p. 160).

Secondly, there's the debate of whether technological change is characterised by a 'deterministic' approach to technology or rather by a 'voluntaristic' one. The former approach stands for 'a metaphysics of technology' as a force manifesting itself in and through history (Scranton, 1995). An example of such a force is the emergence of general purpose technologies. This view has, however, been challenged by the conception of the history of technology as something that faces an environment of serial 'indeterminacies' (see Scranton, 1995). The latter approach, on the other hand, stands for a history of technology predicated on the choices that actors, individually or collectively, make (Barley, 1998).

In addition to these competing narratives regarding the nature of technological change, the literature on history of technology attempts also to uncover the set of interrelated determinants that explain the process of technological change. A useful time sequence of these determinants is provided by the Schumpeterian trilogy of technological change – invention, innovation and diffusion (see Girifalco, 1991; Stoneman and Diederen, 1994). It is possible to include here also the process of decline, i.e., the process of substitution of the old technology for a new one performing the same task.

As Edgerton (1998) points out, much of the literature on history of technology seems to be concerned with the first two determinants of technological change – invention and innovation. However, despite the existing fuzziness that revolves

[2] Such as competence-destroying or competence-enhancing technological shifts (Tushman and Anderson, 1986).

[3] Note that this term has been "originated in biology (...) [and] has been used to characterise evolutionary discontinuities caused by small subgroups of a species becoming isolated, developing a significant trait, and then displacing their 'mother species' in a very short period of time" (Loch and Huberman, 1999).

around the concepts of innovation and diffusion[4] (Devezas, 2005), a number of authors support the idea that the meaning of technological change is essentially commercial. This means that only those technologies that find their way to a market are seen as 'successful'. In fact, Schumpeter suggested in 1834 that the diffusion of major innovations is the driving force behind the business cycle (Köllinger, 2006). Rosenberg (1979, cited in Edgerton, 1998) adds that innovation and "inventions acquire their economic importance, obviously, only as function of their introduction and widespread diffusion" (p. 19; see also Hall, 2004; Hall and Khan, 2003; Ruttan, 2003).

This suggests that the meaning of technological change is essentially related with the process of diffusion (Edgerton, 1998; Sarkar, 1998; Stoneman and Diederen, 1994). Hall and Khan (2003) have extended this argument and pointed out that "understanding the workings of diffusion is essential to understand how technological change actually comes about" (p. 1). The next section takes a closer look to the specific issues surrounding the process of technology diffusion.

2.1. Diffusion of technology and market organisation

The process of diffusion of technology has been studied from a myriad of perspectives, namely the historical, economic, sociological, institutional and network theoretical. In fact, as Ruttan (2003) reminds us, it "has been an important field of inquiry in anthropology since the late 19th century. (...) [It has] emerged as an important research agenda in sociology, primarily in rural sociology, in the 1940s and 1950s (...) [as well] as an increasingly important research agenda in economics during the 1960s. (...) [And, more recently, it] has focused on the international diffusion of technology" (Chapter 6, p. 1).

In this paper special attention is given to the economic dimension of the process of technology diffusion. Much of the research on this topic is focused, on one hand, on modelling the paths of technological diffusion (see, for example, Doessel and Strong, 1991). The first generation of research on diffusion can be traced back to Griliches, in the mid 1950s, and it has proceeded with the work of Mansfielfd, in early 1960s, who have tried to identify regularities in diffusion paths, typically represented by S-shaped curves. A second generation of research emerged in the late 1970s. It employed not only conventional microeconomic equilibrium models, but also a set of evolutionary models (see, for example, Ruttan, 2003; Silverberg et al., 1988).

On the other hand, the research on this topic has also been focused on the identification of the set of factors that explain the process of technology diffusion. Rosenberg (1972) has proposed a broad classification of these factors as the gradual improvements of either the inventions or innovations, the development of the human skills required for both use of new techniques and machine-making itself, the complementaries, the improvements in old technologies and the industry and institutional context. Several other authors, such as or Hall (2004), Nelson et al. (2004), Stoneman and Diederen (1994), have proposed different classifications of these factors.

Despite the apparent existence of a myriad of factors affecting the diffusion of technology, considerable attention is often given in the literature to the issues of industry and institutional context, namely to the market characteristics, which are often cited as core determinants of the rate of adoption of a new technology (Mansfield, 1983; Quirmbach, 1986). These characteristics include the market size, the market structure (both on supply and demand side) for a particular innovation, the market structure for related technologies and the general regulatory and institutional environment (Köllinger, 2006; Stoneman and Diederen, 1994). The latter is of particular importance for traditionally regulated industries such as those of transport and public utilities, given that government action and regulation usually advance the diffusion of innovations which under normal situations would not occur (Dupuy, 1997; Ettlie and Vellenga, 1979; Hall, 2004).

In summary, as a whole, the literature review highlights, on one hand, that the overall process of technological change seems to be mainly driven by diffusion of new technologies, and, on the other hand, that particular attention must be given to role played by the market characteristics in the process of the technology diffusion. These issues are further explored below in the context of the evolution of different modes of urban public transport in Europe.

3. Evolution of modes of urban public transport in european cities

3.1. Innovation and diffusion of urban public transport modes

Public transport in urban areas has been guaranteed by different modes of transport. It includes major systems such as the road and rail network, major devices such as trams and buses, components such as engines and sub components such as wheels and tyres. Each of these parts has a function of its own to support the overall function 'public transport'.

This section takes a closer look at the processes of innovation and diffusion of different modes of transport across different European cities. The analysis will merely focus on transport devices. Dates will be attached to the occurrences, whenever possible. Fig. 1 presents a timeline of the opening and closure of different public transport systems in European cities. For comparison purposes, only the opening and closure of the first fifteen public transport systems are displayed for each public transport mode. Moreover, the timeline also details some of the main historical events that occurred between 1775 and 2000.

[4] As Wright (1997) clearly suggests, there's a "difficulty both in practice and in principle to maintain a clear distinction between innovations in pure 'technology' on one hand, and adoptions or diffusion of already-existing technologies on the other" (p. 1560).

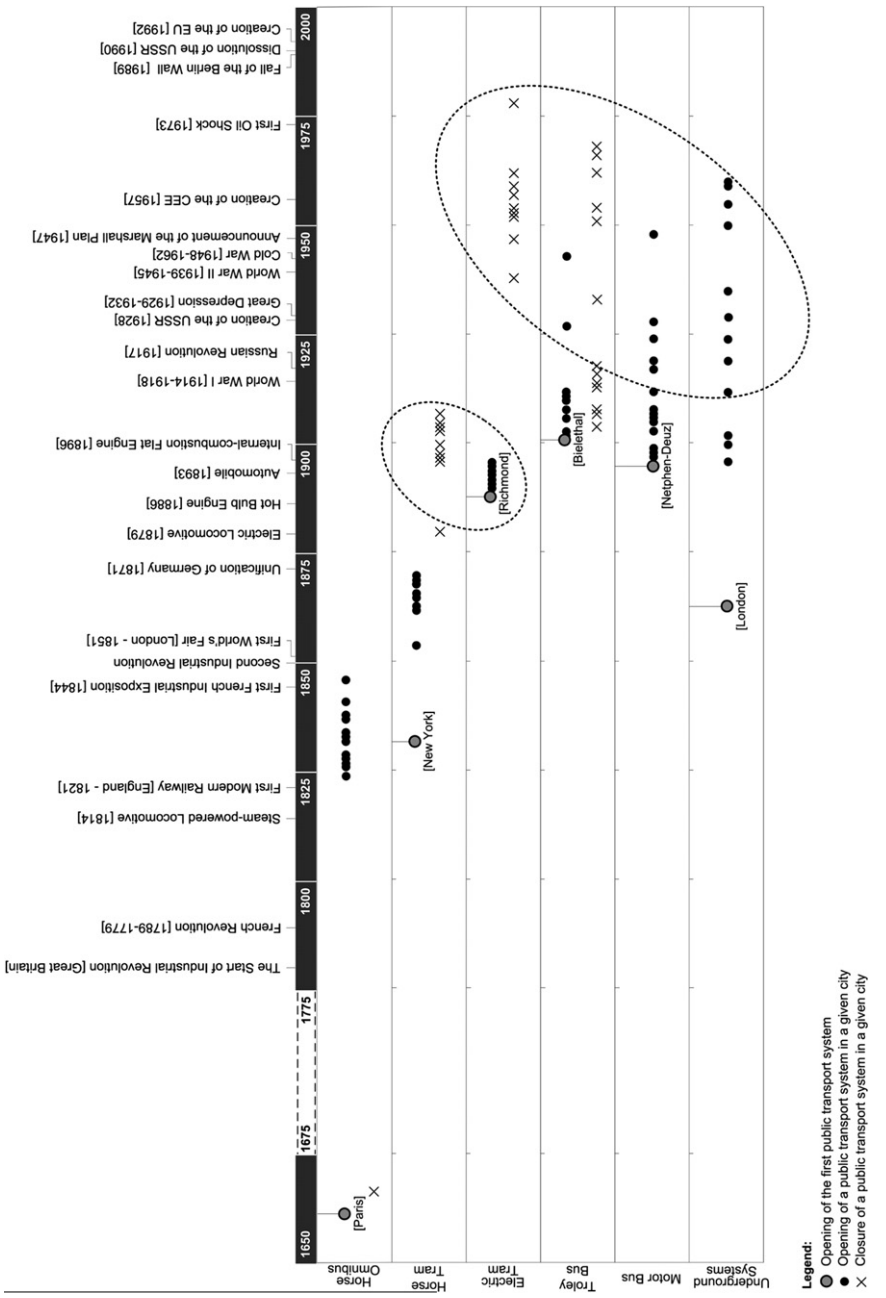

Fig. 1. Opening and closure of public transport systems in European cities.

Table 1
Innovation and diffusion of the horse tram in Europe. *Sources*: Amsterdam (Deacon, 1980, pp. 10 and 23); Antwerp (Keutgens, 1975a, p. 2); Barcelona (Del Castillo and Riu, 1959, p. 21); Berlin, Cologne, Dresden, Frankfurt, Hamburg, Leipzig, Munich and Stuttgart (Hendlmeier, 1981, p. II:11–16); Birmingham (Jenson, 1971, p. 125); Bordeaux, Lyons and Marseilles (Robert, 1974, Table I); Bristol (Cooper, 1974, p. 75); Brussels (Société des Transports Intercommunaux de Bruxelles, 1976, p. 61); Budapest (Carter, 1973, p. 224); Cardiff (Morgan, 1986, p. 178); Constantinople (Hendlmeier, 1981, p. I:31); Copenhagen (Taplin, 1967, pp. 3 and 15); Dublin (Flanagan, 1969, p. 82); Edinburgh (Booth, 1971, p. 35); Geneva (Boegli et al., 1976, p. 21); Genoa (Azienda Municipalizzata Trasporti, 1980, p. 37); Glasgow (Simpson, 1972, p. 150); Lisbon (Companhia Carris de Ferro de Lisboa, 1993, p. 7); Leeds (Dickinson, 1960, p. 215); Liverpool (Bett and Gillham, 1962, p. 23); London (Barker and Robbins, 1963, p. 178; Barker and Robbins, 1974, p. 170); Manchester (Joyce, 1965, p. 24); Madrid (Hendlmeier, 1981, p. I:31); Milan (Cornolò and Severi, 1987, p. 15); Moscow (Arbeitsgemeinschaft Blickpunkt Straßenbahn e.V., 1996, p. 99); New York (McKay, 1976, p. 14); Porto (Pereira, 1995, pp. 34 and 46); Paris (Merlin, 1982, p. 17; Bastié, 1964, p. 129); Prague (Carter, 1973, pp. 211 and 215); Rotterdam (Schoonaard, 1971, p. 7); St. Petersburg (Bater, 1973, p. 88); Sheffield (Hall, 1977, p. 30); Turin (Hendlmeier, 1981, p. I:31); Vienna (Joyce, 1965, p. 56).

Innovation	Diffusion in Europe		Closure
New York (1832/1852)	Paris (1854/1873)	Dresden (1872)	*Stuttgart (1896)*
	London (1861/1870)	Barcelona (1872)	Leipzig (1897)
	Geneva (1862)	Leipzig (1872)	Liverpool (1898)
	Copenhagen (1863)	Turin (1872)	Dresden (1900)
	St. Petersburg (1863)	Moscow (1872)	Munich (1900)
	Berlin (1865)	Birmingham (1872/3)	Manchester (1903)
	Vienna (1865)	Sheffield (1873)	Vienna (1903)
	Hamburg (1866)	*Antwerp (1873)*	*Porto (1904)*
	Budapest (1866)	Lisbon (1873)	*Frankfurt (1904)*
	Stuttgart (1868)	Amsterdam (1875)	*Prague (1905)*
	Brussels (1869)	Bristol (1875)	*Cologne (1907)*
	Constantinople (1869)	*Prague (1875)*	Berlin (1907/10)
	Liverpool (1869)	Marseilles (1876)	London (1914)
	Madrid (1870)	Munich (1876)	Copenhagen (1915)
	Leeds (1871)	Manchester (1877)	Amsterdam (1916)
	Edinburgh (1871)	*Cologne (1877)*	Hamburg (1922)
	Porto (1872)	*Genoa (1878)*	
	Cardiff (1872)	Milan (1878)	
	Glasgow (1872)	*Rotterdam (1879)*	
	Dublin (1872)	Bordeaux (1880)	
	Frankfurt (1872)	Lyons (1880)	

Note: Cities in italics are not among the 36 most populated cities in Europe in 1875, as seen in Chandler and Fox (1974).
Missing information: Naples, Warsaw, Rome and Palermo.

Blaise Pascal was well ahead of his time when he and some friends introduced the public transport service in Paris, in March 1662. They requested permission to explore an omnibus "that would follow the same routes everyday; ... for five sols... and would start everyday at a fixed time, even if few people or any were present without any extra charge for the ones using the service" (Robert, 1974, p. 9). Given the initial success, by July the same year they were operating five lines, one of them circular (Robert, 1974, p. 19). The licence was conceded on the condition that "soldiers, pages, lackeys and other workers" were not allowed to use the service "for the more comfort of people of merit" (Robert, 1974, p. 19). The hostility of the general public to such a pretentious service, the deficient conditions of circulation in the narrow streets of Paris and the increase in the fares to six sols led to the closure of the company, probably in 1677 (Robert, 1974, p. 19).

Even though the first attempt to re-introduce a horse-omnibus service can be traced back to 1st January 1824, when John Greenwood, proprietor of the Pendleton Toll Gates, started a regular horse bus or coach service in Manchester, the transformation of mass transportation into a successful business is generally attributed to a horse omnibus service launched in Nantes by Stanislas Baudry, in 1826.[5] The service was meant to transport people from the centre of the city to some baths he had built in its outskirts but it became very popular with passengers boarding for different destinations along the route (Robert, 1974, p. 21). The baths were never a success and were eventually closed but Baudry extended the transport services to the streets of Nantes (Robert, 1974, p. 21).

The *diffusion* of the horse omnibus service started almost immediately. In 1827, Baudry commenced omnibus operations in Bordeaux. One year later, in 1828, Baudry got permission to explore ten lines, using 100 vehicles, through the streets of Paris (Robert, 1974, p. 21). In the following year, George Shillibeer, a coach builder with interests in Paris, introduced the horse omnibus in London (Barker and Robbins, 1963, p. 20) and Jakub Chocenský obtained the right to operate the omnibus in Prague (Carter, 1973, p. 209). In the 1830s and 1840s many cities saw local entrepreneurs launching the same kind of service: Le Havre in 1832, Geneva in 1833, Birmingham in 1834, Brussels in 1835, Lyons in 1837, Dresden in 1838, Milan in 1841, Portsmouth in 1842 and Berlin in 1846.[6]

[5] Hibbs (1989, p. 25) describes a public transport service launched by John Greenwood in Manchester in 1824, Carter (1973, p. 224) mentions that the horse omnibus was established in Vienna in 1824 and Jenson (1978, p. 18) attributes the merit of starting the service to Jacques Laffite in Paris in 1819 but this fact is generally attributed to Baudry because the service spread to other cities from the knowledge of the success of his experience.

[6] Le Havre (Robert, 1974, p. 431); Geneva (Boegli et al., 1976, p. 19); Birmingham (Jenson, 1971, p. 113); Brussels (Société des Transports Intercommunaux de Bruxelles, 1976, p. 21); Lyons (Robert, 1974, p. 303); Dresden and Berlin (McKay, 1976, p. 11); Milan (Cornolò and Severi, 1987, p. 10).

Table 2
Innovation and diffusion of the electric tram in Europe. *Sources*: Amsterdam (Deacon, 1980, p. 18); Antwerp (Keutgens, 1975a, p. 3); Barcelona (Zurita, 1964, p. 4); Belfast (Flanagan, 1969, p. 72); Berlin, Bremen, Cologne, Dresden, Frankfurt, Hamburg, Leipzig and Munich (Hendlmeier, 1981, p. II:11–16); Birmingham (Klapper, 1974, p. 150; Kay and Cormack, 1977, p. 156); Breslau (Hendlmeier, 1981, p. II:16); Bristol (Cooper, 1974, p. 90); Brussels (Société des Transports Intercommunaux de Bruxelles, 1976, p. 178); Copenhagen (Taplin, 1967, p. 10); Dublin (Flanagan, 1969, p. 82); Edinburgh (Booth, 1971, pp. 37/38); Genoa (Azienda Municipalizzata Trasporti, 1980, p. 96); Glasgow (Simpson, 1972, p. 151; Joyce, 1965, p. 31); Leeds (Dickinson, 1960, p. 218; Kay and Cormack, 1977, p. 156); Lisbon (Companhia Carris de Ferro de Lisboa, 1993, p. 10); Liverpool (Bett and Gillham, 1962, pp. 22 and 23); London (Barker and Robbins, 1974, p. 15; Kay and Cormack, 1977, p. 156); Lyons and Paris (Robert, 1974, Table I); Manchester (Joyce, 1965, pp. 24 and 25); Madrid (Empresa Municipal de Transportes, 1992a,b); Milan (Cornolò and Severi, 1987, p. 19); Moscow (Arbeitsgemeinschaft Blickpunkt Straßenbahn e.V., 1996, p. 99); Porto (Pereira, 1995, p. 46); Prague (Carter, 1973, p. 215); Richmond (McKay, 1976, p. 49); Rotterdam (Schoonaard, 1971, p. 7); St. Petersburgh (Bater, 1973, p. 92); Sheffield (Hall, 1977, p. 71); Vienna (Joyce, 1965, p. 56).

Innovation	Diffusion		Closure
Richmond (1888)	*Bremen (1890)*	Glasgow (1898)	Paris (1938)
	Berlin (1890)	Liverpool (1898)	Manchester (1947)
	Leeds (1891)	Copenhagen (1899)	London (1952)
	Paris (1892)	Frankfurt (1899)	Birmingham (1953)
	Lyons (1893)	Moscow (1899)	Belfast (1954)
	Dresden (1893)	Sheffield (1899)	Liverpool (1957)
	Genoa (1893)	Barcelona (1899)	Lyons (1957)
	Milan (1893)	Amsterdam (1900)	Leeds (1959)
	Breslau (1893)	Birmingham (1901)	Glasgow (1962)
	Hamburg (1894)	Cologne (1901)	Hamburg (1978)
	Brussels (1894)	London (1901)	
	Bristol (1895)	Lisbon (1901)	
	Munich (1895)	Manchester (1901)	
	Porto (1895)	Antwerp (1902)	
	Dublin (1896)	Belfast (1905)	
	Leipzig (1896)	Rotterdam (1905)	
	Prague (1896)	St. Petersburg (1907)	
	Vienna (1897)	Edinburgh (1910/1922)	
	Madrid (1898)		

Notes: Electric tram with electricity by overhead wire. Cities in italics are not among the 41 most populated cities in Europe in 1900, as seen in Chandler and Fox (1974).
Missing information: Constantinople, Budapest, Ruhr, Warsaw, Naples, Odessa and Turin.

The horse tram was the second mode of transport widely used in public transport in urban areas. The horse tram became viable with the solution of the problem of the height of the rail achieved in 1852 with an experiment carried out in New York under the supervision of the French engineer Alfhonse Loubat (McKay, 1976, p. 14). This was a significant innovation because the first trams had used rails placed above street level and such rails interfered with the other traffic which created public hostility (McKay, 1976, p. 14). The horse tram used the horse power, the operators' main expense, much more efficiently than the omnibus and it was safer, more comfortable, faster, smoother and less noisy (Barker and Robbins, 1963, pp. 178–179). In spite of these advantages the horse tram needed the construction of the track and so the omnibus remained with a niche in the market in the places where this was not justifiable or where opposition to track laying arose. Table 1 shows information related to dates of diffusion of the horse tram in some of the most populated European cities in 1875. It took 10 years from the introduction of the horse tram in New York to have a regular horse tram service in a major European city and it took nearly another two decades to have the tram in all of them.

The productivity of the service had increased with the horse tram and lower fares were possible but the costs of operation were still high, the fares were above what the worker in a low income could afford and several attempts to mechanise the tram took place (McKay, 1976, pp. 37–39). Steam power was introduced in some cities but generally over short periods of time and was of little significance (*e.g.* Steam tram in Antwerp 1888–1891, Copenhagen 1884–1892, Munich 1883–1900, one line in Porto 1878–1914 and funiculars in Lisbon 1889–1927).[7] The same happened with the cable tram with the exception of Edinburgh where the cable network was from 1900, quite extensive. The system started to be built in 1888, was greatly extended in 1900, but the operation was very complex and in 1922 and 1923, was converted to electric traction (Hunter, 1954; Booth, 1971).

The electric tram was the *technological innovation* that provided a cheap form of transportation and a *swift increase* in public transport utilisation. McKay (1976, p. 241) says:

> "... I would argue that the change from animated-powered transport of the age of walking cities and horse-drawn vehicles, including tramways, to inanimate, mechanized, mass-produced, and mass oriented urban public transportation has occurred only once. For Europe, that once was with electric streetcars. Thereafter urban public transportation has evolved with buses, high-speed trains, express subways, etc., or even declined where the harmful consequences of basing urban civilization upon the private automobile have been grossly underestimated, as in the United States. But it has not been revolutionized".

[7] Antwerp (Keutgens, 1975a, p. 3); Copenhagen (Taplin, 1967, p. 4); Lisbon (Companhia Carris de Ferro de Lisboa, 1993, p. 12); Munich (Hendlmeier, 1981, p. II:13); Porto (Pereira, 1995, p. 48).

Table 3
Comparisons of rise and decline of electric tramway operations. *Source*: Souter (1996, p. 188).

Country/Group	GB	F	BX	D	CH	A	H	CS	PL	SD	IB	I
% open												
By 1.1.1895	5	6	6	8	8	13	7	4	3	3	2	2
By 1.1.1900	19	39	11	20	36	40	38	41	46	14	11	15
By 1.1.1905	79	67	37	59	57	50	53	59	65	42	41	28
At 1.1.1950	16	36	83	89	77	73	92	93	90	92	84	73
At 1.1.1960	4	7	57	73	64	63	92	74	87	64	58	27
No. of operators	196	163	49	236	83	22	13	27	32	39	(34)	(99)
Year 50% open	02	00	06	02	02	03	00	01	00	07	06	09
Year 50% closed	35	45	61	69	67	76	NA	NA	NA	71	63	54

GB – British Isles: F – France (1930): BX – Netherlands + Belgium + Luxembourg: D – Germany (E + W) (1950): CH – Switzerland: A – Austria: H – Hungary: CS – Czechoslovakia: PL – Poland (1950): SD – Sweden + Norway + Finland + Denmark: IB – Spain + Portugal: I – Italy: NA – Not Applicable: Data relates to national boundaries as at year given: () incomplete data.

The electric tram was made possible because of several technical developments. Siemens built for the Berlin Industrial Exhibition of 1879 the "first practical electric train in the world with current taken from a stationary generator" but the power supply was still from a third rail but in the Paris exhibition in 1881 Siemens experimented with the first overhead conductors with copper wire (McKay, 1976, pp. 37–39). In the beginning of the 1880s, in spite of some technical difficulties, some electric tramway systems with underground supply were built in holiday resorts (McKay, 1976, pp. 37–39). These systems had operational costs similar to those of the horse tram[8] which were profiting from the favourable state of the hay and grain market experienced after the mid-1870s (Barker and Gerhold, 1995, p. 47) and even more in the middle 80s.[9]

In 1888, in Richmond, Virginia, USA, the American Julian Sprague built the first network with equipment able to provide a regular service, without major disruptions, with the electric supply by overhead wires (McKay, 1976, p. 49). Sprague's system, as well as Thomson–Houston's one, enabled a reduction in working expenses of about 45%.[10] This information spread quickly and Richmond "became the mecca of railway operators and investors" (McKay, 1976, p. 202). Other cities had the system built in a few years as shown in Table 2. Incremental technology and the gains in the phase of learning by doing were also important (Dawson, 1895, p. 144)[11]. Fares went down, public transport was then affordable for those on a low income and utilisation increased sharply (McKay, 1976, p. 202).

The electric tram was a perfect substitute for the horse tram which entered a period of rapid decline and most systems were soon closed as shown in Table 1. Within 2 years of Sprague's success in Richmond the electric tram with overhead wire was operating in Europe and, with few exceptions, within 10 years the major urban centres had an electric tramway system.

Electric trams still operate in some Western European cities but the development of the trolleybus and the motor bus resulted in the abandonment of many electric tramway lines. The choice of public transport modes with the horse tram and electric tram was clear, so great were the advantages of these new modes of transport over the existing ones everywhere. The substitution of the electric tram was a more complex decision. The process of substitution was influenced by the economic environments experienced in different countries. Table 3 shows that the opening of the electric tramway systems occurred approximately at the same time everywhere in Europe but the closure of the undertakings occurred much sooner in Great Britain and France than anywhere else.

The main cost differences between the electric tram, the trolleybus and the motor bus over a period of four decades or so were the ones related to initial investments. The operational costs of the electric tram and trolleybus were comparable from the 1910s (Gribble, 1915, pp. 52–53) and the operational costs of the electric tram, trolleybus and motor bus were possibly comparable in the 1920s, 1930s, 1940s and 1950s. The abandonment of the tramway was related to the huge investments needed for track replacement but the moment of the abandonment of specific services was influenced by several different factors, internal and external to the industry.[11] The electric tram kept its competitiveness longer in large cities without underground systems because the capacity of the tram ensured a better position to deal with heavy traffic than other modes. In small cities the tram's struggle to survive began earlier.

The first operational trolleybus line was opened in 1901 in Bielethal, in Germany, but being unprofitable, closed in 1904 (Kuipers, 1977, p. 58). Several other lines opened in the following years across Europe but most of them had to close before the 1920s (Kuipers, 1977, p. 58). Taking France as an example, all the initial trolleybus systems had very few vehicles (Montaubau was the most extensive with five vehicles) and closed within a few years of their opening dates (*e.g.* Paris 1900–1900/1912–1913, Lyons 1901–1907, Marseilles 1902–1908, Saint Malo 1906–1907, Fontaineblau 1901–1913, Mulhouse 1908–1918 and Montaubau 1903–1904) (Robert, 1974, Table II). During the 1910s in Britain the trolleybus started to present some advantages over the electric tram and with the increasing utilisation of the tyre in the 1920s the trolleybus appeared to be the natural successor to the tramway. Design improvement resulted in greater reliability, comfort and higher

[8] *The Engineer*, 1890, (April 25), 342.
[9] *Engineering*, 1887, (November 18), 530.
[10] *The Engineer*, 1890, (April 25), 342.
[11] Souter (1996, p. 187) summarises the factors pointed by Ian Iearsley and Buckley and establishes an extensive list of external factors.

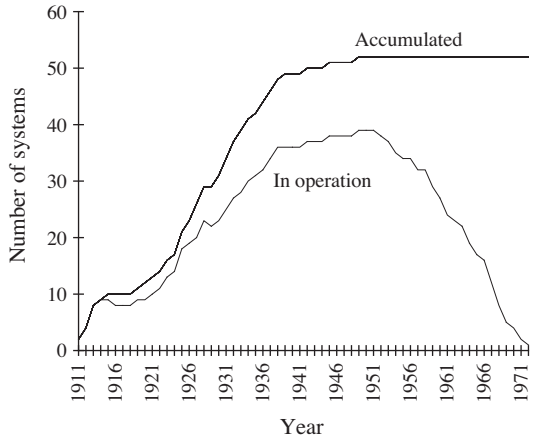

Fig. 2. Total number of trolleybus systems operating in each year and accumulated value in Britain. *Source*: Kay and Cormack (1977, p. 150). (Brearley (1966) reports similar information. There are minor differences in dates of opening and number of systems. Brearley (1966) includes information on the dimension of trolleybus operators.)

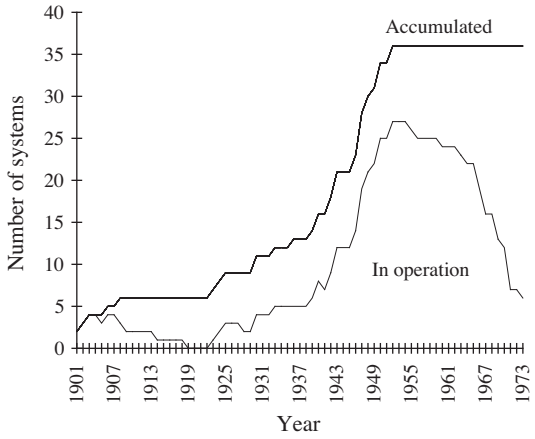

Fig. 3. Number of trolleybus systems operating in each year and accumulated value in French urban areas. *Source*: Robert (1974).

speed (Pilcher, 1937, p. 135). The operational costs were about the same as the bus which was much noisier and polluted more.

By the 1930s the trolleybus had "advanced from a position in which it was regarded in the main only as suitable as a means of developing short lengths of route preliminary to tramway operation, to that in which it" was then "considered capable of replacing complete tramway systems" (Pilcher, 1937, pp. 135 and 137). Some regular trolleybus systems were constructed in Britain and Germany in the 1910s (*e.g. Dresden 1903–1904, Bremen 1910–1916, Leeds 1911–1928, Bradford 1911–1972, London 1912–1914*). *Nevertheless*, in Britain, as well as in Ireland, most of them were built during the 1920s and 1930s (*e.g.* Birmingham 1922–1951, Manchester 1938–1966, Belfast 1938–1968). In France and Germany most systems were built during the 1940s and beginning of the 1950s (*e.g.* Dresden 1947–1975, Bremen 1949–1961).

The introduction of the trolleybus was linked, in many cases, to secondary reasons. Difficulties in obtaining petrol after World War II and the long life span of some electric equipment that could be used from the tramway network favoured the introduction of the trolleybus.

In Britain the involvement of municipalities in the production of electricity also affected the decision to adopt the trolleybus. That might be the main reason why Britain had regular trolleybus services before other countries. The decline started in the 1950s and most systems closed during the 1960s. By then the advantages of the motor bus were clear. The price of petrol had been decreasing for a long period and operational costs had gone down. The trolleybus did not have the flexibility of the bus and road repairs, accidents and power failure could bring the whole system to a halt. Figs. 2 and 3 show the diffusion and decline of the trolleybus in British and French towns.

The motor bus was the mode that widely took over as the main mode of public transport in urban areas. The first motor bus service opened in 1895 between the cities of Netphen and Deuz in Germany, with buses built by Benz (Kuipers, 1977,

Table 4
Innovation and diffusion of underground systems in Europe. *Sources*: Union International des Transports Publiques (1964) and Jane's urban transport systems.

Innovation	Diffusion in Europe		
London (1863)	Glasgow (1896)	St. Petersburg (1955)	Vienna (1976)
	Budapest (1896)	Lisbon (1959)	Lyons (1978)
	Paris (1900)	Kiev (1960)	Marseilles (1978)
	Berlin (1902)	Milan (1964)	Newcastle (1980)
	Hamburg (1912)	Oslo (1966)	Helsinki (1982)
	Madrid (1919)	Frankfurt (1968)	Lille (1983)
	Barcelona (1924)	Rotterdam (1968)	Kharkow (1984)
	Bucharest (1929)	Munich (1971)	Novosibirsk (1985)
	Moscow (1935)	Nuremberg (1972)	Toulouse (1993)
	Stockholm (1950)	Prague (1974)	
	Rome (1955)	Brussels (1976)	

Table 5
Phases of evolution of market characteristics of transport modes.

Mode	Phases		
	Entrepreneurial	Consolidation	Public involvement
Horse omnibus	Yes	Yes	No
Tram	Yes (Horse tram)	Yes	Yes (Electric tram)
Trolleybus	No	No	Yes
Motor bus	Yes/no	Yes/no	Yes
Metro	Yes/no	Yes/no	Yes

p. 4). Approximately around 1905 the motor bus was presenting advantages in relation to the horse omnibus which, in spite of high operational costs, was still in use because of its flexibility. The motor bus was a good substitute for the horse omnibus and in virtually 10 years the horse omnibus disappeared from the cities where it had survived (*e.g.* Paris in 1913 and London in 1914),[12] giving way to the electric tram. However, the process of diffusion was slow because it took time to develop many engineering parts such as the body, engine and tyre. The introduction of the motor bus was attempted early in some cities (*e.g.* Bradford in 1897, Edinburgh in 1898, London in 1899, Birmingham in 1903, Paris in 1905, Barcelona in 1906, Vienna in 1907, Amsterdam in 1908 and Lisbon in 1912). Nevertheless, the provision of regular services has occurred much later in most of European cities (*e.g.* Bergen in 1917, Edinburgh from 1919, Leicestershire in 1919, Amsterdam and Barcelona from 1922, Moscow in 1924, Strasburg in 1928, Lisbon from 1944 and Porto in 1948).[13] The motor bus became gradually more competitive in areas of low density.[14] "Some years before motor buses were supposed to have become competitive with the trams as far as working costs were concerned, trams were already becoming uneconomic because of their intrinsic high capital replacement costs" (Buckley, 1989, p. 104). In the 1950s with the fleet fully dieselised, new metal bodies which meant lower maintenance costs and the raising of the bus/employee productivity the advantages of the motor bus were greater (Buckley, 1989, p. 109).

Underground systems were built in some of the larger European urban areas because the degree of congestion already experienced in the road network led to the need for dedicated public transport corridors. The number of buildings in city centres made the construction of open air railway lines impossible, such would be the amount of destruction and monetary compensation needed to impose such a solution. The underground offered the best form of providing a service of high frequency and high capacity, matching the needs of the ever larger cities. In 1863 London, the largest city of the time with around 3 million inhabitants, was the first to construct a metro, powered with steam. Glasgow and Budapest followed in 1896, with a cable and a electric system respectively, and Paris in 1900 with an electric system. London started electrification in 1890 and Glasgow changed from the cable system to electric power in 1935.

The construction of an underground line demanded huge amounts of capital. In the first systems the construction was done by the cut-and-cover principle (*e.g.* London and Paris) with lines following the road network but with the improvement of engineering techniques in the construction of tunnels, construction became less disruptive of urban life. Construction costs differed considerably between cities (Reilly, 1992, p. 104). Table 4 gives the opening dates of the underground systems in Europe.

3.2. Evolution and organisation of public transport markets

Public authorities have gradually increased their involvement in the provision of public transport services in urban areas. In the beginning, with the horse omnibus, markets were very competitive and the involvement of local public authorities

[12] Paris (*Engineering*, 1922, (June 16), 740); London (Hibbs, 1989, p. 69).
[13] Amsterdam (Deacon, 1980); Barcelona (Zurita, 1964, p. 8); Edinburgh (Hibbs, 1989, p. 42; Booth, 1971, p. 37); Lisbon (Companhia Carris de Ferro de Lisboa, 1993, p. 12).
[14] *Engineering*, 1913, 779–780.

was confined to the granting of licences and law enforcement. Nowadays the involvement of public authorities extends, in many cases, to the point of actual operation of the transport service itself. Between these two extreme situations a variety of combinations have existed and continue to exist.

Three phases in the longer term evolution of urban public transport market can generally be identified:

(1) an *entrepreneurial stage* when the mode of transport first emerged. This phase was characterised by great dynamism and frequent market instability needing considerable entrepreneurial ability to survive[15];
(2) a period of *agreements, mergers and consolidation* in an attempt to increase profits and economic rents or achieve market stability to improve the prospects of staying in the market. The consolidation was achieved either through fare and service agreements between the operators or promoted by public authorities with the granting of monopoly licences;
(3) a period of *public involvement* in which public authorities assumed the responsibility of operating urban public transport services. This public involvement had its greatest expression in Britain with the increasing involvement of municipal corporations in urban services. The justification of the municipal enterprise was put forward in the following terms: "At first private individuals with capital behind them relieved the authorities of certain duties. Then they joined hands and the company became a public servant. But as towns increased in wealth, and more able men went into office and public opinion strengthened, with an eye to greater perfection in public service, Parliament began to grant to the municipal corporations the privilege of doing their own work. The opportunity for self-employment, the sense of co-operation, and the personal interest of the public has increased this. This may be the *raison d'être* of municipal socialism in England" (Gibbons, 1901, p. 248).

Not all modes of public transport experienced these three phases and certainly this did not happen in the same form or at the same time in every urban area. However, as in the case of diffusion of modes of transport, the similarities in experiences between cities are impressive. Table 5 offers the phases of evolution generally experienced by each mode of transport.

The *horse omnibus* went through the first two phases: an entrepreneurial stage and a phase of agreements, mergers and consolidation.

The entrepreneurial stage was difficult and most of the initial entrepreneurs had to close their businesses within a few years of their opening. For example, Baudry (Nantes and Paris) became bankrupt and committed suicide in 1830 (Robert, 1974, p. 21); Schillibeer (London) saw all his property seized in 1836, fled to Boulogne to escape his creditors and, on his return to Britain spent several months in prison (Barker and Robbins, 1963, p. 29); the two initial companies formed in Birmingham were last mentioned in 1838 and 1843 (Jenson, 1978, p. 34); while the service started in Prague was prone to failure from the beginning (Carter, 1973, p. 209).

The usual advantages of arriving first in the market (first mover advantage) did not exist. In the large cities the closures occurred because competition was fierce, the markets were very unstable and many of the initial entrepreneurs could not survive in such an environment. In other cities there was not enough demand and the conditions of operation in the narrow streets of city centres was difficult.

The process of agreements between operators to combat instabilities started almost from the beginning (*e.g.* London since 1831, as stated by Barker and Robbins, 1963, p. 23). More important consolidations were achieved either by the concession of monopoly licences (*e.g.* Paris and Lyons in 1855) or by attempts to create private monopolies (*e.g.* London in 1856).

In Paris, after the introduction of the horse omnibus in April 1828, the number of operators spread: there were three operators by the end of 1828 and ten by the end of 1829 (Robert, 1974, p. 21). Competition, however, was fierce, several regroupings and mergers occurred and new companies were formed. The intervention of the Chief Constable Piétri (Merlin, 1982, p. 17) and the Prefect Haussman, led to the merger in 1855 of the existing 10 companies to form the Compagnie Générale des Omnibus, which received monopoly operating rights for 30 years (Robert, 1974, p. 23). The same happened in Lyons with the merger of the six existing companies in 1855 and the creation of Compagnie Lyonnaise d'Omnibus which obtained the monopoly of omnibus operation (Robert, 1974, p. 24). In these two French cases, public authorities took an active role in the process of consolidation.

In 1855 the Compagnie Générale des Omnibus de Londres (later renamed London General Omnibus Company – LGOC) was formed in Paris. During 1856 the company managed to buy operators owning 600 out the 800 vehicles of the existing stock and established agreements with most the remaining ones (Barker and Gerhold, 1995, p. 47). The Parisian experience highlighted the advantages of monopolies in the operation of public transport and a similar market structure was tried in London. The company "achieved economies of scale in the purchase and processing of horse feed and in stabling" (Barker and Gerhold, 1995, p. 47).

The *tram* experienced each of the three phases of evolution identified previously. From the beginning, using horse power, two institutions emerged: the public authority which regulated the tramways but did not operate them and the private operators which had the concessions to build and operate the tramways in public streets for private profit (McKay, 1976, pp. 18–19).

The entrepreneurial phase was smooth. The need for track construction in public road and acquisition of vehicles led to the granting of long term concessions. The ownership of these long term concessions had some economic value. The various urban markets were stable but relations between the authorities and the operators were generally rather poor with Glasgow

[15] In economic terms this type of situation is said to be characterised by the lack of a 'core'.

Table 6
Dates of electrification and creation of monopolies of tram networks. *Sources*: Electric tram taken from Table 2. Amsterdam (Deacon, 1980, pp. 17–18); Antwerp (Keutgens, 1975a, pp. 3–6/7); Barcelona (Del Castillo and Riu, 1959, p. 194); Belfast (Flanagan, 1969, p. 72); Berlin (Walker, 1965, p. 46); Birmingham (Jenson, 1971, p. 146); Cardiff (Morgan, 1986, p. 182); Copenhagen (Taplin, 1967, pp. 5 and 14–15); Edinburgh (Booth, 1971, p. 37); Frankfurt (Yago, 1984, p. 91); Glasgow (Klapper, 1974, p. 211); Leeds (Soper, 1985, p. 107); Lisbon (King and Price, 1983, p. 10); Liverpool (Bett and Gillham, 1962, p. 23); London (Barker and Robbins, 1974, p. 282); Madrid (Empresa Municipal de Transportes, 1992a,b); Milan (Cornolò and Severi, 1987, p. 26); Porto (Pereira, 1995, pp. 44 and 142); Paris (Robert, 1974, p. 129); Prague (Carter, 1973, p. 92); St. Petersburg (Bater, 1973, p. 63); Sheffield (Hall, 1977, p. 63); Vienna (Havers, 1966, p. 195).

	Electric tram	Private monopolies	Public involvement
Amsterdam	1900	–	1900
Antwerp	1902	1901	s. 1945
Barcelona	1899		1952/53
Belfast	1905	–	1904
Berlin	1890	–	1918
Birmingham	1901	–	s. 1904 c. 1911
Cardiff	1902	–	s. 1902 c. 1903
Copenhagen	1899	1898	s. 1911 c. 1919
Edinburgh	1910/1922	–	1919
Frankfurt	1899	–	1898
Glasgow	1898	–	1894
Leeds	1891	–	1894
Lisbon	1901	1892–1896	1973
Liverpool	1898	–	1897
London	1901	–	1933
Madrid	1898	1920	1933
Milan	1893	1897	1917
Porto	1895	1893	1946
Paris	1892	–	1921
Prague	1896	–	s. 1898 c. 1907
St. Petersburg	1907	–	s 1898
Sheffield	1899	–	1896
Vienna	1897	–	1903

Note: s. started, c. completed.

representing, probably, the extreme case. A major difficulty was that operators and municipalities did not share the same objectives. The operators wanted to maximise profits and the municipalities wanted to develop the transport network and expand the physical limits of the cities. Concessions were normally granted line by line or over small areas and, more rarely, for the entire area of a city. Antwerp, Berlin, London, Madrid, Lisbon and Paris enjoyed a relatively large number of operators but in other cities, such as Amsterdam, Porto and Prague, the number was limited to just one or two.

A more deep consolidation of markets was attained at the time of electrification because, with the exception of larger cities, it was not feasible to have several operators electrifying the streets. The industrial organisation of the market became monopolistic or, at least, there was a greater degree of concentration. The consolidation was achieved in one of three ways: monopolies or oligopolies created by the private organisations, merging their companies or buying the competitors (*e.g.* Porto in 1893, Lisbon between 1892 and 1896, Copenhagen in 1897), granting of monopoly licences to a private operator (*e.g.* Milan in 1897, Antwerp in 1902) or municipalisation (*e.g.* Amsterdam in 1900, Frankfurt in 1898).

Table 6 shows the dates of electrification together with the creation of private and public monopolies in selected European cities.

The first municipalisation of a wide scale network took place in Glasgow, in 1894. The service was already consolidated into one operation at the time of municipalisation but there were considerable conflicts between the operator and the corporation (McKay, 1976, pp. 173–174). Disputes over conditions of contract renewal led to the decision by the authorities not to extend the contract (McKay, 1976, p. 174). Given the subsequent success of this municipalisation, in spite of the initial difficulties, many cities followed the experience. As can be seen from Table 6, many transfers to public ownership took place in the late 1890s and beginning of 1900s.

Two main reasons, not necessarily independent, seem to have contributed to the involvement of public authorities in the operation of the tramway systems: the high profitability of tramway operations and conflicts stemming from the different objectives of operators and authorities. Some cities after transferring the operators to public ownership pursued similar economic criteria to the private operators. This led in Britain to enquires by Parliamentary Commissions. Gibbons (1901, p. 254) reports that in one of those enquires "Mr. Garcké, by means of a chart, showed that most municipal undertakings were being run with a view to profit, and, therefore he was opposed to the majority of them". Glasgow (Simpson, 1972, p. 152) and Cardiff (Morgan, 1986, pp. 188–189) are among those cities that kept the same criteria of investment of the private operators. For other cities, the transference to public ownership of the tram network was a determinant factor in the implementation of policies of quick network construction and city expansion (*e.g.* Frankfurt, Yago, 1984). A third reason to transfer operators to public ownership was related to the fact that knowledge of the success of first public involvement in the operation spread fast – there was a strong positive, demonstration effect.

The introduction of the electric tram affected the structure of transport markets to such an extent that from then onwards urban public transport markets were generally seen as almost natural public monopolies.

The *trolleybus* became competitive when the operation of electric trams was already in public ownership. The trolleybus could use, with some amplifications, the same infrastructure of power supply and wires already built for electric trams (Pilcher, 1937, p. 137).

There were some early attempts by private entrepreneurs to introduce trolleybuses in France and Germany but eventually all of them had to close. In fact in France Lombard-Gérin, wishing to promote his invention, was responsible for a number of these early attempts (Courant and Bejui, 1985, p. 7). Very few vehicles were used (Robert, 1974, Table II).

The characteristics of transport markets supplying *motor bus* services varied between cities mainly because the process of diffusion was very slow. The electric tram brought the municipalisation of the service. This affected the market characteristics of trolleybus operations because of the similarities in their operating conditions. The motor bus resembles the omnibus in that its operation is very flexible, the sunk costs are not great and one man enterprises are possible. However, with few exceptions, the fierce competition experienced in horse drawn omnibus markets was not to be repeated. Motor bus markets were consolidated and public authorities were more involved in public transport issues.

The entrepreneurial phase took place in an era in which the motor bus still experienced many technical problems and frequent breakdowns would disrupt the service. Even after London and Paris had regular bus services, attempts to introduce the motor bus were unsuccessful in many other cities.

In cases where competition did evolve, agreements and mergers prevailed and in other cases an operator enjoyed a monopoly of operations. Tramway companies were well established in the public transport market and in many cases they were responsible for the introduction of the motor bus. In other cases they bought out the enterprises competing with their service (*e.g.* Antwerp). "In cases where foresight has been shown, the tramways undertaking has operated buses, abandoned the tram routes and extended its services. Where vision has not been shown and the tramway system has been adhered to, the undertaking has gone out of business" (Pilcher, 1937, p. 111).

The first *underground* system opened in 1863 in London but Table 4 shows that most of the existing ones in Europe opened more than a hundred years later. At the time of the construction of the underground in London, municipalisation was not an issue but, in 1896, when the underground opened in Glasgow, municipalities were starting to become involved in public transport provision.

The first underground systems experienced the three phases of evolution of market characteristics. The first and second phases were strongly linked because construction implied a strong degree of concentration. Private entrepreneurs assumed the responsibility of constructing and exploring the underground service in London, Glasgow and Madrid. Public authorities became involved because private operators were struggling to deliver the service (*e.g.* one line in Paris in 1920, Glasgow in 1922, Madrid in 1978/79).

Most underground systems were built in the last 40 years or so and only experienced the last phase of evolution of market characteristics. The system in Paris opened in 1900 and was built by public authorities for private exploration. Only one line was constructed and explored by private entrepreneurs but was municipalised in 1920.

Involvement of public authorities in the provision of several modes of urban transport led afterwards to the creation of *transport commissions* in many European metropolitan areas, with the possible exception of London, where the commission was created in 1933 at the same time as municipalisation. Transport commissions were created in order to bring all public owned operators under the same management (*e.g.* Berlin in 1929, Paris in 1948, Madrid in 1985, Barcelona in 1997 and Lisbon in 2009). This would make possible the co-ordination of services and the introduction of fare systems common to all public owned operators.

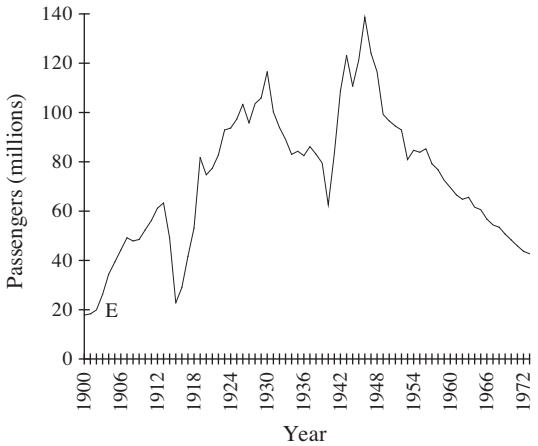

Fig. 4. Public transport utilisation in Antwerp. *Source*: Keutgens (1975b, p. 411).

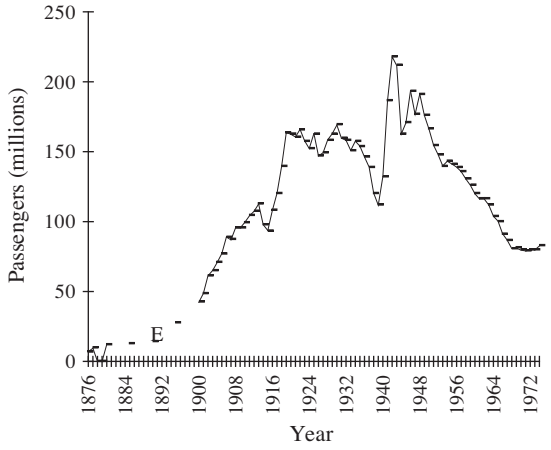

Fig. 5. Public transport utilisation in Marseilles. *Source*: Laupiès and Martin (1975, p. 590).

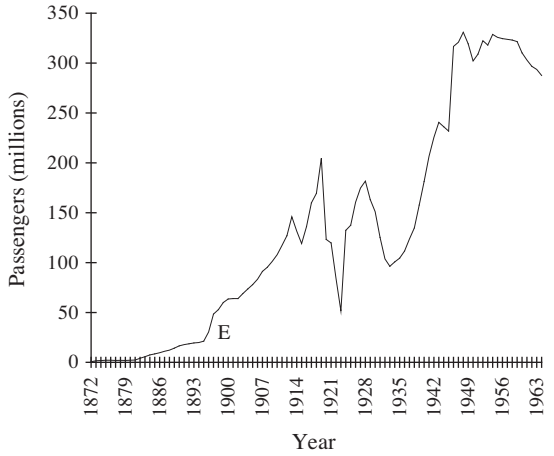

Fig. 6. Tram utilisation in Leipzig. *Source*: Adam et al. (1966, pp. 240–242).

4. Discussion

In the previous sections, a historical overview of the introduction and diffusion of different transport modes across European cities and the evolution and organisation of public transport markets was presented.

In general terms, the historical records analysed in this paper showed, on one hand, that the adoption of each public transport mode in European cities presented some similarities, supporting Barker's (1980) argument that "The new forms of transport were available everywhere within a very short period of time of their being shown to be commercially viable anywhere. Their economic and social effects, once introduced, are likely to have been similar" (89). It also showed that the evolution of market characteristics in European cities relating to each form of transport also presented some similarities. The consolidation of markets has generally been favoured. Private entrepreneurs tried to create monopolies through mergers or to obtain them through the ownership of a monopoly licence. Public authorities supported the creation of these monopolies and gradually became involved in the provision of public transport services.

On the other hand, despite the apparent existence of similarities in the adoption of each public transport mode in European cities, the historical records presented in this paper also indicated that the paces of diffusion of each public transport mode varied considerably from case to case. Fig. 1 clearly shows that the introduction and diffusion of electric tram systems across European cities took virtually only a few years, whereas the diffusion of previous and subsequent modes of public transport occurred at a much slower pace, extending, in some cases, over a period of several decades.

Even though the variations in the paces of diffusion of different public transport modes may be somewhat explained by the occurrence of specific historical events, such as the World War I and the Great Depression in the case of the trolley bus and the difficulties in obtaining petrol after World War II in the case of the motorbus, we believe that the success of a particular public transport mode, measured by the pace of its diffusion, has been mainly related to two factors: technology and

costs. Our argument is that there was a potential market to explore and any new mode of transport able to drive the costs down and provide a reliable, comfortable and safe service was likely to be successful.

The case of the introduction of the electric tram in European cities clearly illustrates this situation. On one hand, as discussed in Section 2, public transports became only affordable for workers in a low income with the introduction of the electric tram, which was the technological innovation that provided a cheap form of transportation. Their preceding counterparts – the horse omnibus and the horse tram, had such high operation costs that the fares were above what the worker in a low income could afford. On the other hand, the level of utilisation of public transports increased sharply with the introduction of the electric tram and kept increasing until intensive use of the private car changed this trend. Figs. 4–6, which show the number of passengers in Antwerp, in Marseilles and in the tramway system in Leipzig, provide clear evidence for this argument. The evolution in the number of passengers in each of these cities followed similar patterns and the impact of the introduction of the electric tram can be easily spotted: Antwerp from 1902, Marseilles from 1892 and Leipzig from 1896.

Therefore, the case of the electric tram shows that the reduction in operation costs that was enabled by the introduction of a new technology (the electric tramways) appears to have resulted in the sharp increase in the demand for public transports in European cities. On the other hand, the increase in the utilisation of urban public transports that followed the introduction of the electric tram appears to be the reason why the diffusion of electric tramways in European cities was so fast in comparison with the diffusion of the horse omnibus and horse tram. In fact, as highlighted in Fig. 1, such was success of the electric tram that the horse tram entered in a period of rapid decline only a few years after the introduction of the first electric tramway in Europe.

Moreover, even though the introduction of tramway systems enabled, by itself, a remarkable reduction of operational costs, Section 3 showed that the opening of the electric tram in European cities just became economically feasible with the consolidation of the markets relating to this urban transport mode at the time of electrification. Similarly to the cases of the horse omnibus and horse tram, such consolidation was largely attained by the creation of monopolies and oligopolies through mergers and the granting of monopoly licences to a private operator by local authorities or municipalisation. The main difference now was that it enabled the provision of affordable transport services and, concurrently, the increase in the demand for public transports.

Another difference was that after the consolidation of the markets relating to the electric tram, public authorities became gradually involved in the operation of tramway systems. In Section 3, we argued that a major contributor to the transfer of private operators to public ownership was the profitability of tramway operations. Taking into account that the level of utilisation of public transports may be viewed as measure of the profitability of public transport services, the argument that the involvement of public authorities in tramway operations was mainly profit-driven appears to be supported by Figs. 4–6, in that the utilisation of public transports increased sharply after the introduction of the electric tram in European cities.

On the other hand, the slower pace of diffusion of subsequent urban transport modes – the trolley bus, motor bus and underground systems, appears to be explained by the inability of these new technologies to provide more effective and cost-competitive public transport services compared with the electric tram. Note that, as explained in Section 2, the operational costs of the electric tram, trolley bus and motorbus were comparable from the 1920s to the 1950s. Moreover, the development of underground systems was faced with the problem of the huge amounts of capital needed for construction of tunnels. Therefore, the introduction and diffusion of the trolley bus, motor bus and underground systems appear to have been mainly driven by changes in technology rather than by cost and efficiency differences between these systems and the electric tram. This means these new technologies were not perfect substitutes for the electric tram, whose decline only occurred several decades after the introduction of the first motorbus, trolleybus and underground system in European cities (as highlighted in Fig. 1) and was mainly related with the huge investments needed for track replacement and other factors external to the industry.

As a final remark, it is worth noting that the discussion carried out in this section appears to support McKay's (1976) argument that urban public transport in Europe has been revolutionised only once – with the introduction of the electric tram and, more specifically, with the deep transformations that it operated in the structure of transport markets.

5. Conclusions

Two general conclusions can be extracted from the analysis of the historical records presented in this paper. Firstly, the case of the electric tram showed how the changes in the structure of transport markets, which enabled the provision of affordable and more reliable public transport services, had a significant impact in the level of utilisation of public transports and promoted the quick replacement of previous public transport systems (namely the horse tram).

Secondly, the cases of the trolleybus and, in particular, of the motorbus and underground systems showed how the introduction of new technologies that were not perfect substitutes for existing technologies (the electric tram) struggled to find their way to the market. Note, on one hand, that the rates of adoption of these urban transport modes in European cities were much slower than the rate of adoption of the electric tram. And that, on the other hand, the decision of abandonment of electric tramway systems was mainly influenced by factors internal and external to the industry.

The main findings of the paper may provide some insight into the process of diffusion of more recent urban transport modes. Taking rapid bus transit as an example, we wonder if the reason why this new transport modes has not been yet widely adopted in European cities may be somewhat related to its inability to provide more effective and cost-competitive services in comparison to existing public transport modes.

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