An International Review of The Significance of Rail in Developing More Sustainable Urban Transport Systems in Higher Income Cities

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Introduction

With growing attention being paid to sustainability issues, most cities are making efforts to restrain the growth in automobile dependence. Many avenues are available to cities in the pursuit of this goal. Physical planning policies can aim to make development more compact with mixed land uses, thus building in less auto-dependence at the start (Cervero 1998, Newman and Kenworthy 1999a). Economic policies towards the automobile can seek to minimise car ownership and use through higher prices that perhaps better reflect the car's true social cost, as has happened in Singapore for example (Ang 1990, 1993). Amongst these efforts, there is a general recognition that the role of public transport needs to be enhanced, along with its companion modes, walking and cycling, and the latter for reasons of health, not just transport (Pucher 2002, Pucher and Dijkstra 2003).

Within this general recognition that public transport can play a much greater role in most cities, arguments exist about the most appropriate modes to install to achieve enhanced public transport use and other desirable qualities, such as cost-effectiveness, integration with land uses and ability to shift people out of cars. In particular, there is considerable debate about buses versus rail (e.g. Henry 1989, Pickrell 1990). Some argue that rail is very capital intensive and that well-conceived bus systems can achieve the same results at a fraction of the cost (Bonsall 1985, Kain and Liu 1999). This argument is strongly used in lower income cities where there appears to be less financial capacity to afford the extra capital costs of rail systems (Badami 2005). Others argue that rail systems in general have greater intrinsic passenger appeal and that they compete better with cars (Newman and Kenworthy 1991). Hass-Klau et al (2003) have made extensive studies of European cities with and without light rail systems and have concluded strongly that those cities that develop LRT systems consistently outperform, across many criteria, those cities that attempt to run their public transport systems only using buses.

Likewise, a report from Litman (2004) of the Victoria Transport Policy Institute called 'Rail Transit In America: Comprehensive Evaluation of Benefits' evaluates rail's benefits in terms of transport system performance in 130 U.S. cities. It finds that cities with large, well-established rail systems have a wide range of system-wide benefits relative to those that have no urban rail (see later).

It is further argued that rail stations are natural sites for dense residential and mixed-use development which can help to reshape the city into a more sustainable urban form (Cervero 1995, Kenworthy 1995, Cervero 1998, Newman and Kenworthy 1999a, Hass-Klau, et al 2004).

In order to contribute a more international perspective on the issue of the merits of rail in cities, this paper will explore a wide range of transport, economic and environmental features in

60 higher income metropolitan areas that have strong urban rail systems compared to those that have weak rail systems or no rail systems at all. The term 'cities' in relation to data in this paper refers generally to whole metropolitan regions, not the smaller administrative unit at the heart of the region, which often bears the same name (e.g. City of New York etc.). Higher income cities were defined for the purposes of this research as those with annual GDPs per capita of $US10 000 or more (i.e. it embraced those cities that are generally perceived as being part of the 'developed world', as opposed to cities that are clearly in developing nations). It will examine the evidence for whether urban rail in a city's public transport system appears to make any observable, statistically significant difference to the broad patterns of transport and related factors at a metropolitan scale.

Method

This paper draws upon the Millennium Cities Database for Sustainable Transport developed by Kenworthy and Laube (2001), which in turn built on and extended earlier work by Newman and Kenworthy (1989) and Kenworthy and Laube (1999). Some details about items in the Millennium database, including definitions of indicators and methodologies behind the research can be found in Kenworthy and Laube (1999), Kenworthy and Laube et al (1999) and Newman and Kenworthy (1999a). More specific details about other variables in the Millennium database are available from the author.

The list of 24 'strong rail', 28 'weak rail' and 8 'no rail' cities involved in the research in this paper, together with their 1995/6 populations, appears in table 1. Rail in this study is defined as the combined modes of trams, LRT, metro and suburban rail. The strong rail cities (SRCs) have been defined using three criteria:

- To be classed as a SRC, cities were required to have more than 50% of their total public transport task (public transport passenger travel measured as passenger kilometres) on rail, the weak rail cities (WRCs) have rail systems that account for less than 50% of their total public transport passenger kilometres and no rail cities (NRCs) have either no rail systems or rail systems that are so negligible in terms of extent and usage as to be tantamount to having no rail. Cities in table 1 that fulfill this last criterion are Tel Aviv, Denver, Los Angeles and Taipei where rail usage in 1995 is negligible due to the existence of only very small rail systems.

- SRCs also had to have no less than 40% of total public transport boardings by rail modes.

- Finally, for classification as a SRC, cities were required to have rail systems that are competitive with the car in speed terms. The overall average speed of all rail modes in each city was calculated, weighted by passenger hours, and expressed as a ratio of the average road traffic speed. Only those cities with an average rail speed that was equal to or greater than 0.90 of the road speed were classed as SRCs. Most SRCs exceeded this criterion, often by a considerable margin.

STRONG RAIL CITIES	POPULATION (1995/6)	WEAK RAIL CITIES	POPULATION (1995/6)	NO RAIL CITIES	POPULATION (1995/6)
Washington	3,739,330	Calgary	767,059	Ottawa	972,456
New York	19,227,361	Atlanta	2,897,178	Denver	1,984,578
Brisbane	1,488,883	Chicago	7,523,328	Houston	3,918,061
Sydney	3,741,290	S. Francisco	3,837,896	L. Angeles	9,077,853
Wellington	366,411	Montreal	3,224,130	Phoenix	2,526,113
Barcelona	2,780,342	San Diego	2,626,714	Bologna	448,744
Berlin	3,471,418	Toronto	4,628,883	Taipei	5,960,673
Berne	295,837	Vancouver	1,898,687	Tel Aviv	2,458,155
Brussels	948,122	Melbourne	3,138,147		
Frankfurt	653,241	Perth	1,244,320		
Hamburg	1,707,901	Amsterdam	831,499		
London	7,007,100	Athens	3,464,866		
Madrid	5,181,659	Copenhagen	1,739,458		
Munich	1,324,208	Dusseldorf	571,064		
Oslo	917,852	Graz	240,066		
Paris	11,004,254	Helsinki	891,056		
Ruhr	7,356,500	Lyon	1,152,259		
Stockholm	1,725,756	Marseille	798,430		
Stuttgart	585,604	Nantes	534,000		
Vienna	1,592,596	Rome	2,654,187		
Zürich	785,655	Geneva	399,081		
Osaka	16,828,737	Glasgow	2,177,400		
Sapporo	1,757,025	Newcastle	1,131,000		
Tokyo	32,342,698	Manchester	2,578,300		
		Milan	2,460,000		
		Hong Kong	6,311,000		
		Singapore	2,986,500		
		Seoul	20,576,272		

Table 1: Strong rail, weak rail and no rail cities in the study

The Millennium Cities Database contains complete data for 84 metropolitan areas worldwide, of which 24 can be considered as lower income (i.e. with a GDP per capita of less than $US10 000 per annum). All of these cities, apart from those in Eastern Europe and South Africa, are clearly located in ‘developing nations’. However, Eastern European cities such as Prague in 1995 had low GDPs per capita but cannot be considered as ‘developing cities’, whilst South African cities present a starkly mixed picture whose GDPs per capita are low because of the huge majority poorer populations. Attempts were made to conduct the analysis of the role of urban rail in all these lower income cities as well, but by the criteria just described, only three of these 24 cities could be considered as having strong rail systems. A larger sample of lower income cities worldwide for which comprehensive and reliable data were available would yield more SRCs so that the analysis could be meaningfully conducted, but this was not possible for this paper. The focus of this paper is therefore on cities in the 'developed world', as shown in table 1 whose GDPs per capita range from $US10 305 up to $US54 692 per annum.

Tables 2 to 7 systematically examine how the strong rail, weak rail and no rail cities perform on a wide range of factors using 1995/6 data. The values for each variable in the tables are the medians for the three groups of cities, since the data in each case are generally skewed distributions where the median value is a better representation than the mean. In order to test the statistical significance of the difference amongst the medians, the nonparametric Kruskal-Wallis test from SPSS was used. The Kruskal-Wallis test is used for simultaneously testing multiple cases and eliminates the increased probability of significant results that occurs where, in this case, three separate pair-wise tests could have been undertaken for each variable. Since the samples are relatively small and the asymptotic significance value is not accurate enough, the Monte Carlo simulation of the Kruskal-Wallis test was employed using 100 000 iterations, which gives a 99% confidence level for the p-value (significance of the difference in the medians for each variable). P-values of 0.05 or less (95% confidence level) were considered statistically significant and these are shown in the last column of each table, with significant results marked with an asterisk*.

Urban form and GDP

Table 2 shows the differences in urban form between the groups of cities, as reflected by density and centralisation of jobs, as well as economic differences in the cities expressed through the GDP per capita of the urban regions.

Although urban densities are systematically higher in the cities with rail and lowest in the no rail cities, the result is not statistically significant. Since density is a powerful determinant of transport patterns, especially private car use (e.g. Kenworthy and Laube et al 1999, Newman and Kenworthy 1999), it is useful for the purpose of this research that differences in densities between the three groups of cities are not significant. On the other hand centralisation of the city, as measured by the proportion of metropolitan jobs in the CBD, is clearly highest in the SRCs (18.2%) and lowest in the NRCs (10.2%) and the differences are statistically significant. This might be expected, given the link between radial urban rail systems and the development of strong city centres, through rail's capacity to deliver large numbers of people into small areas (Thomson 1978).

Amongst these high-income cities, the SRCs are clearly wealthier than both other groups of cities in a statistically significant way, and as the next section shows, they are also more public transport-oriented. This undermines the idea that cities inevitably become more auto-dependent and move inexorably away from public transport as they become wealthier. In this significant international sample of higher income cities, the reverse would appear to be true. We have argued elsewhere that excessive automobile dependence drains the economy of cities and there is some tacit support for this in the results in table 2 (e.g. see Kenworthy et al 1997).

The additional relevance of some of these data to the arguments made in this paper will become more apparent in later discussions.

Urban form and GDP	**Strong Rail Cities**	**Weak Rail Cities**	**No Rail Cities**	**p-value**
Urban density (persons per ha)	47.6	36.6	27.7	0.453
Job density (jobs per ha)	27.4	16.1	13.4	0.293
Proportion of jobs in the CBD (%)	18.2%	14.6%	10.2%	0.008*
Metropolitan GDP per capita (US$1995)	$35,747	$26,151	$27,247	0.014*

Table 2: Median values and statistical significance for urban form and GDP in strong, weak and no rail cities (1995)

Operational performance of public transport

Table 3 examines differences in public transport operational performance (service and use). The first item reveals a key basis for the formation of the groups of cities. It shows how the SRCs clearly rely much more heavily on rail systems to deliver public transport mobility, with a median value of 74% of passenger kilometers on rail modes, compared to 43% and 0.4% respectively for the other two groups of cities.

Looking more broadly at the public transport operational measures, table 3 shows that the supply of public transport service rises systematically from NRCs to SRCs for both vehicle and seat kilometres of service per capita. SRCs have over four times higher seat kilometres of service per capita than the NRCs. In usage, there is the same ascending pattern from NRCs to SRCs for boardings, passenger kilometres and the proportion of total motorised passenger kilometres on public transport. Public transport use is some three to four times higher in the SRCs than in the NRCs, depending on the measurement used. This is especially interesting in the light of the urban density data in table 2, which show that there is no statistically significant difference in the median population and job densities between the three groups of cities.

Interestingly, however, despite these big differences in the supply and use of public transport, per capita use of public transport energy is only some 1.6 times higher in the SRCs than in the NRCs, though the difference amongst the medians on this factor is statistically significant. This demonstrates the intrinsically high energy efficiency of public transport systems in providing mobility (i.e. service and use are four times higher in the SRCs compared to the NRCs, while energy use to run the systems is only 1.6 times higher).

Public transport operational performance indicators	**Strong Rail Cities**	**Weak Rail Cities**	**No Rail Cities**	**p - value**
Percentage of pubic transport passenger kms on rail	74%	43%	0.4%	0.000*
Annual public transport vehicle kilometres of service per capita	77	50	29	0.000*
Annual public transport seat kilometres of service per capita	4,086	2,704	969	0.000*
Annual public transport passenger trips per capita	275	188	77	0.002*
Annual public transport passenger kms per capita	1,628	975	496	0.000*
Percentage of total motorised passenger km on public transport	21.8%	12.3%	5.3%	0.004*
Annual public transport energy use per capita (megajoules: MJ)	1,107	880	675	0.019*

Table 3: Median values and statistical significance for operational performance of public transport in strong, weak and no rail cities

Overall, each of the factors in table 3 varies in a strong, statistically significant way in favour of greater rail-orientation of the city. This suggests that for public transport to maximise its role within the passenger transport systems of cities in the developed world, it would appear necessary to move increasingly towards urban rail as the backbone and mainstay of those systems.

Transport infrastructure and infrastructure performance

Table 4 presents a range of public and private transport infrastructure parameters for the three groups of cities.

The data on the extent of transport infrastructure and infrastructure performance reveal, not unexpectedly, that the SRCs have very significantly higher reserved public transport route on a spatial and per capita basis. The vast majority of reserved right-of-way (ROW) in cities is rail; physically segregated busways are very rare (which can be inferred from the fact that in the NRCs, which have either no or negligible amounts of rail ROW, the quantity of reserved public transport route in total is indeed very small).

The SRCs have the lowest total per capita road supply and lowest per capita freeway provision of all three groups of cities and the NRCs have the highest. For example, the NRCs have 71% greater per capita supply of freeways than the SRCs and 65% greater road provision. Although in both cases the differences amongst the median values between the groups are not significant, the consistent direction of the results suggests that higher income cities with more significant rail systems appear to be able to function with fewer roads and freeways.

Perhaps not surprisingly, the data show that SRCs have very much reduced parking supply in their CBDs (68% less than the NRCs), as do WRCs (48% less than NRCs). This is due to rail's capacity for effectively delivering high volumes of people into constrained sites such as CBDs and sub-centres, which eliminates the need for the extensive CBD parking areas found in cities that have no rail systems. Thomson (1978) found similar results in his 'strong-centre' cities.

Transport infrastructure and performance indicators	**Strong Rail Cities**	**Weak Rail Cities**	**No Rail Cities**	**p-value**
Total length of reserved public trans. routes per 1000 persons	172	78	7	0.000*
Total length of reserved public transport routes per urban ha	9.0	3.0	0.4	0.000*
Length of road per capita (metres)	3.0	4.1	5.8	0.398
Length of freeway per capita (metres)	0.070	0.098	0.120	0.282
Parking spaces per 1000 CBD jobs	186	303	585	0.002*
Total private and collective passenger VKT per km of road	2,026,433	1,461,402	1,615,749	0.708
Overall public transport system speed (km/h)	31.3	23.8	22.6	0.000*
Ratio of public transport system speed to road traffic speed	0.86	0.70	0.49	0.000*

Table 4: Median values and statistical significance for transport infrastructure and infrastructure performance in strong, weak and no rail cities

Finally, the data in table 4 show that in the high-income cities, the intensity of road usage or congestion, as measured by the total private and collective passenger VKT per kilometre of road, is highest in the SRCs, but the differences in the medians are statistically very insignificant. The more important point here, however, is not so much the level of congestion as the competitiveness between private and public transport. In this respect it is very clear that the more rail-oriented the city, the higher the overall average public transport speed for all modes (39% higher in SRCs compared to NRCs) and the higher the ratio between the overall speed of the public transport system and the speed of general road traffic. The median value of this ratio for SRCs is 0.86, while for the NRCs it is only 0.49, which suggests that in speed terms public transport will generally struggle against the car in wealthier cities with no rail systems, while in cities with strong rail systems, public transport speed competitiveness will be much better.

The results for both the overall speed of public transport and the speed ratio between public transport and general road traffic are statistically very significant with p-values of 0.000 in each case. It has been suggested elsewhere that it is this relative speed between public and private transport that is a critical factor in giving public transport a competitive edge over private transport (Laube 1998, Newman and Kenworthy 1999a, b).

Overall, it can be suggested that rail systems help in minimising the amount of road, freeway and parking infrastructure required in cities and are a central ingredient in developing public transport systems that can successfully compete with cars in the critical area of travel speed.

Private transport patterns

Table 5 provides a core set of data related to patterns of private transport and broader modal split in the three groups of cities.

The data reveal that in terms of modal split, there is a systematic pattern in these high-income cities of enhanced use of both non-motorised modes and public transport and reduced use of private modes the more rail-oriented are the cities, and the results have a high level of statistical significance. For example, in the SRCs, the median value for the percentage of total daily trips by private transport is 47%, whilst in the NRCs, it is 84%. The WRCs also have only 56% of daily trips by private transport. Likewise, the median value for non-motorised mode use is almost three times greater in the SRCs than the NRCs, while public transport use for daily trip making is some four times higher.

Despite this modal split pattern, table 5 reveals that there is very little difference between the car ownership and actual car travel (VKT and passenger kms per capita in cars and motor cycles) in SRCs and WRCs. However, there is a considerable difference between these more rail-oriented cities and the cities with no rail, though overall the differences amongst the medians are not statistically significant. Despite this lack of overall statistical significance amongst the medians, the NRCs do have about 70% higher median car use than both the SRCs and WRCs.

Private transport indicators	**Strong Rail Cities**	**Weak Rail Cities**	**No Rail Cities**	**p-value**
Total cars and motor cycles per 1000 people	463	476	544	0.256
Private passenger vehicle VKT per capita (cars + mc)	5,133	5,151	8,732	0.276
Private vehicle passenger kilometres per capita (cars + mc)	6,981	7,014	11,736	0.252
Percentage of all trips by non-motorised modes	31.2%	20.8%	11.3%	0.001*
Percentage of all trips by public transport	19.3%	13.8%	4.7%	0.007*
Percentage of all trips by private transport	47.5%	56.3%	83.8%	0.000*

Table 5: Median values and statistical significance for private transport indicators in strong, weak and no rail cities

What is quite interesting about this pattern of private transport use is its relationship to the density and GDP data presented earlier. First, there is a very strong and statistically significant negative relationship found between urban density and private transport use per capita in the higher income cities in this study (R^2 of 0.8392); it is virtually the strongest correlation found between all the variables in the entire database. As such it could be expected that the NRCs, with a lower median value of urban density (27.7 per ha) than the SRCs (47.6 per ha), would tend to have higher car use per capita, just based purely on their more sprawling land use patterns. Based on the equation of the regression curve between urban density and car passenger kilometres per capita, the NRCs could be expected to have approximately 2 700 more car passenger km per capita than the SRCs. In fact, the difference in Table 5 is 4 700, perhaps suggesting that without the superior public transport systems of the SRCs, the NRCs struggle to substitute car use with public transport use. There is some support for this suggestion in the literature in what is known as the 'transit leverage effect' where one passenger km of public transport travel replaces multiple kilometres of travel in cars (Neff 1996, Newman and Kenworthy 1999).

Furthermore, it is clear that the SRCs in this study have significantly higher GDP per capita than either the WRCs or the NRCs (37% and 31% respectively: see table 2). It is thought by some commentators that greater wealth in a city tends inevitably towards higher automobile dependence and therefore that the SRCs would be unlikely to have equal or lower car use than the WRCs and NRCs with their considerably lower GDP per capita (Gomez-Ibañez 1991, Lave 1992). Again, it would appear that the NRCs are experiencing considerably higher dependence on the car than either their urban form or wealth characteristics would point towards.

The data on private transport and overall modal split strongly suggest that rail is a significant factor in minimising automobile dependence in cities in the developed world. Strong rail systems apparently help in developing urban characteristics that together favour less private transport use (though not necessarily statistically significant lower car + motor cycle ownership), and greater capacity to exploit both public transport and non-motorised modes.

Economic factors

Table 6 summarises some important indicators of the economic performance of urban systems in relation to transport.

Many discussions on the overall effectiveness of urban public transport systems focus on the 'subsidy' afforded to public transport, particularly as reflected in the operating cost recovery of the system. Whilst it can be argued that this focus constitutes a very limited view of the significance of public transport systems in keeping a city operating effectively and minimising environmental impacts (e.g. none of public transport's benefits to non-users such as congestion minimisation appear on the credit side of the balance sheet), and that the word 'subsidy' is something of a misnoma, it is nevertheless important to examine this factor. The data show that it is the SRCs that have the best recovery of operating costs (60%) with WRCs at 51%, while the NRCs recover a much lower figure of 35% and these differences in the medians are statistically significant. Although the differences in average public transport vehicle occupancy in table 6 are not statistically significant, the SRCs do have 16% higher occupancy than the NRCs, which would partly explain the better cost recovery result. Rail cities tend to concentrate public transport services into more focussed corridors with more transit-supportive land uses, which generally deliver higher patronage per unit of service supplied. On the other hand, cities with no rail or those relying solely or almost solely on buses, tend to have public transport systems that have to 'chase' fewer patrons through lower density settings, which inevitably detracts from higher rates of cost recovery.

Economic indicators	**Strong Rail Cities**	**Weak Rail Cities**	**No Rail Cities**	**p-value**
Public transport operating cost recovery (%)	60%	51%	35%	0.037*
Overall public transport vehicle occupancy	19.8	17.8	17.0	0.192
Percentage of metro GDP spent on public transport investment	0.42%	0.20%	0.10%	0.000*
Percentage of metro GDP spent on road investment	0.73%	0.72%	0.88%	0.774
Total passenger transport cost as percentage of metro GDP	9.03%	9.27%	11.78%	0.018*

Table 6: Median values and statistical significance for economic indicators in strong, weak and no rail cities

The other three economic items in table 6 refer to how much of the GDP of the cities is spent on investing in their public transport and road systems and how much of their GDP they spend on passenger transport as a whole (both public and private transport operating and investment costs from all sources). The patterns are quite clear and statistically significant: the more rail-oriented the cities, the greater proportion of their GDP goes back into investment in their public transport systems, and the lower is the overall cost to the society of running the entire passenger transport system (9.0% of metro GDP in SRCs compared to 11.8% in NRCs). The cities with rail also spend less of their GDP on road investment, but the overall differences in the median values between the groups of cities is not statistically significant on this factor because of the virtually identical result between the SRCs and WRCs.

In summary, the economic data suggest that in this sample of developed world cities, those where rail is a strong feature have greater wealth and more cost-effective urban transport systems overall. They are also investing more in the quality of their public transport systems. Such cities would appear to be wasting less economic resources on passenger transport functions and on this factor are therefore likely to be more competitive economically than cities which sink a higher proportion of their wealth into transport functions.

Environmental factors

Transport systems produce a range of environmental impacts, taken here to include energy use and deaths attributable to transport accidents. Table 7 highlights the relatively favourable position of the more strongly rail-based cities in minimising these impacts.

Per capita use of energy in private passenger transport increases as cities become less rail-oriented, with the NRCs being 144% higher in this factor than the SRCs. Because the SRCs and the WRCs do not vary very much in their median values, the overall differences in the medians are not statistically significant, even though there is this clear difference in private transport energy use between cities that have rail and those that don’t (as there was with car use in table 5).

Per capita generation of local smog producing emissions from transport (nitrogen oxides, carbon monoxide, sulfur dioxide and volatile hydrocarbons) is also much higher in the NRCs than in the SRCs (100% higher). The pattern of decreasing per capita transport emissions is quite systematic as the strength of rail increases, though the result falls a fraction short of statistical significance at the 90% confidence level. The spatial intensity of smog emissions also rises slightly the less rail-oriented the cities become, but the results fall far short of any statistical significance (the median value for the NRCs is only 6% higher than the SRCs).

Finally, the costs incurred through transport-related accidents in cities are significant, especially the loss of life. The data in table 7 reveal a consistent and statistically significant pattern of increasing transport deaths as the cities become less rail-oriented and of course less public transport-oriented as a whole. This is true both for per capita transport deaths, which are 129% higher in the NRCs than in the SRCs, and also deaths per billion passenger kilometres, which are 58% higher. It would appear that the more rail-oriented cities become, the less exposure there is to the risk of death from transport causes, even though the use of the riskier non-motorised modes also increases with greater rail orientation.

Environmental indicators	**Strong Rail Cities**	**Weak Rail Cities**	**No Rail Cities**	**p-value**
Private passenger transport energy use per capita (MJ)	16,381	17,197	39,951	0.317
Total transport emissions per capita (NOx, CO, SO2, VHC: kg)	96	114	195	0.105
Total transport emissions per urban hectare (kg)	3,538	3,663	3,753	0.692
Total transport deaths per 100,000 people	5.8	7.8	13.3	0.000*
Total transport deaths per billion passenger kms	6.4	8.0	10.1	0.017*

Table 7: Median values and statistical significance for environmental indicators in strong, weak and no rail cities

In summary rail systems, through their capacity to reduce car use and enhance public transport and non-motorised mode use, are associated with cities that use lower energy for passenger transport and generate lower local emission loads and transport deaths, both on a per capita and per passenger kilometre basis.

Discussion

The findings in this study are in line with extensive and detailed work by Hass-Klau et al (2003), Hass-Klau et al (2004) and Hass-Klau and Crampton (2002), which has demonstrated the many system-wide benefits in European cities of having Light Rail Transit (LRT) systems compared to only having bus systems, including busways. These benefits include higher public transport patronage, which was also found in this international study, but also a wide range of benefits in other factors, which were not examined in this study, but which help perhaps to understand the favourable results found for rail modes in this international comparison. Even though their work refers specifically to LRT systems, some of the findings are likely to be extendable to rail systems in general. Some of their key findings were:

- LRT requires the least width of corridors – busways require most width.
- LRT normally transports more

passengers per hour than standard buses.

- Noise and pollution are lowest with LRT
- Running comfort is best with LRT
- LRT is better in overall urban design terms
- LRT and busways are very similar in cost
- LRT vehicles cost much more but have the longest life expectancy
- LRT is slightly cheaper than buses, on a whole-life basis for similar levels of service.
- Complementary measures are critical to the success of public transport (parking cost and availability, land use policies, pedestrianisation, urban design)
- Buses need stronger complementary measures in order to reach their maximum potential.
- Complementary measures are easier to implement with LRT and important to do in all transport projects to maximise the benefits of the investment.
- Political and psychological factors related to different transport modes modify financial considerations e.g. successful pedestrianisation schemes are strongly linked to implementation of LRT systems.
- Under equal conditions people prefer to use LRT than to use buses.
- There are a higher percentage of higher income groups using light rail than buses (e.g. in Calgary, Canada).
- LRT has a strong potential following among car users, even in cities with no recent experiences of LRT or trams.

The study by Litman (2004) comparing 130 US cities with and without rail concluded that those with significant rail systems have:

- Lower per-capita traffic congestion costs.
- Lower per-capita traffic fatalities.
- Lower per capita consumer transport expenditures.
- Higher per capita public transport ridership.
- Higher public transport commute mode split.
- Lower public transport operating costs per passenger-mile.
- Higher public transport service cost recovery.

Of the above factors that were examined in this international study, the results were similar. The Litman study found that residents in cities with large, well-established rail systems enjoy about half the per capita traffic congestion delay as people who live in comparable size cities that lack rail. The reason for this is in line with the findings in this international study that people in cities with rail systems enjoy lower per capita annual vehicle kilometres whilst also having an effective alternative when travelling on the most congested corridors. Litman (2004) also found that US cities with large rail systems have about a third lower per capita traffic fatality rates. Residents of the strong rail cities also save approximately $US450 annually per capita in transport costs compared with residents of cities that have no rail systems. The study concluded that rail system service costs are repaid several times over by reduced congestion, road and parking facility costs, reduced traffic accident costs, and consumer cost savings. Such findings are in line with the observed comparative differences in this sample of high-income cities around the world that have rail systems (e.g. lower CBD parking, lower transport deaths, a lower proportion of metropolitan GDP being spent on passenger transport, better cost recovery for public transport, higher public transport use).

Rail also has important impacts on urban form in terms of its capacity to increase densities and consolidate both residential and mixed use development around centres or nodes or along corridors. The positive land use impacts of urban rail and their transport flow-on effects are partly responsible for the urban system benefits outlined in this paper. Nodes of development are easier to service with public transport (including bus systems), walking and cycling are more viable for more trips and a polycentric city based around rail stations can help to minimise urban sprawl. These aspects of urban rail and its city-shaping capacity are discussed in detail in other works (Vuchic 1981, Bernick and Cervero 1997, Cervero 1998, Laube, Kenworthy and Zeibots 1999, Newman and Kenworthy 1999a).

Conclusions

Any developed city wishing to build a better public transport system, to curb or reduce its automobile dependence and to become more environmentally and economically sustainable, should not ignore the potential benefits of building a strong rail backbone as the mainstay of the city's public transport system. The data in this paper point strongly to the idea that public transport systems based on buses alone cannot achieve the same positive urban system results across a wide range of factors as when rail systems assume a more significant role within the public transport system.

The mechanisms for the advantages of urban rail are complex. However, they appear to relate at least in part to the legibility of rail systems and the greater permanence of rail services, the positive image of rail in the mind of the public and business community and people's willingness to use rail systems over buses for a variety of reasons, including more competitive travel speed and greater reliability and quality of service.

None of this, however, diminishes the critical role that buses play in public transport systems. Buses are essential public transport providers to areas that simply cannot be served by rail and there are many such areas in most cities, and buses provide critical feeder systems into major sub-centres and into rail systems. Well-patronised urban rail systems are usually associated with strong and healthy levels of bus use (Kenworthy and Laube 2001). Where network structures are well devised and services well coordinated, rail and bus are highly complementary and are not in competition with each other, but rather form an integrated, multi-modal public transport system that provides competition with the car.

Finally, the arguments and research put forward in this paper should not be read or construed in terms putting one mode of public transport above another merely for the sake of it. This is clearly not productive since the best public transport systems emerge out of choosing the right mode for the right task for the multitude of situations in any city. Public transport should be seen as a multi-modal system whose chief aim is to compete with and reduce dependence on the car, building a 'virtuous circle' rather than a cycle of decline, which has tended to be the story of public transport in so many cities over the last decade (Kaufmann 2000). Rather, what the paper has shown is that urban systems, whether in auto-dependent North America or Australia, more transit-oriented Europe, or the wealthier parts of Asia, do seem to gain multiple benefits from developing public transport systems that are anchored and shaped primarily by fixed-track modes, the vast majority of which are rail systems, in one form or another. This then forms the basis for a superior overall public transport system, utilising rail modes, buses and in some cases ferries, which fills a much greater role in the city's transport system.

Finally, it needs to be said that although the analysis in this paper is based on data from 1995 or 1996, the overall conclusions and patterns between the three groups of cities are unlikely to be altered were the analysis to be conducted using later data. In other words, the systematic differences in the various factors found between strong rail, weak rail and no rail cities are not ephemeral observations, but are based on strong structural differences between the cities, which reveal themselves repeatedly over long periods of time. A similar analysis was carried out with 1990 data on a more limited set of cities listed in Newman and Kenworthy (1999a). The same systematic patterns of variation between the rail cities and no rail cities emerged on the same variables.

In addition, the author has begun the update of data on some cities, especially in the USA and the completed transit data for 2005 shows that the US cities with no rail, such as Phoenix, continue to stagnate in transit use with only an 11% increase in annual boardings per capita from an extremely low level of 15.1 trips per capita up to 16.8 (virtually the lowest in the world). Phoenix is building a LRT system at this moment. Likewise Houston declined slightly in transit use over the 10 year period and has finally voted to build an extensive LRT system. Los Angeles in the mean time has been aggressively growing its rail system (light rail, metro and commuter rail) and has achieved the highest growth rate in transit use of all the US cities studied (39%, up from 49.1 boardings per capita in 1995 to 68.3 in 2005). New York, the most rail-oriented of the US cities, was the other big transit winner with a 28% increase in transit use from 131.5 boardings per capita to 167.7 per capita, the bulk of which came from the NY underground. Thus more recent data are tending in the direction of reinforcing the patterns observed in this paper, so that the ageing nature of the data used do not undermine the policy value of the results and conclusions.

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