Transport impacts of the Copenhagen Metro

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Abstract

The Copenhagen Metro is the main improvement made to Denmark's urban public transport infrastructure in the last decade. The most important argument in favour of a new public transport system in the capital was to increase market share for public transport, thus reducing car traffic and environmental impact and enhancing urban development, especially on the island of Amager, whose only previous link to the city was a bus service.
Keywords: metro system, transport impact, panel survey.

1 Introduction

1.1 The Copenhagen Metro

In 1992, the Danish Parliament passed the Ørestad Act permitting the construction of a new railway infrastructure in Copenhagen. The government thus endorsed the regeneration of public transport and the reduction of road congestion in the Danish capital. Of the three suggested public transport modes – metro, light rail and tram – the first option was chosen. Metro construction started in 1996 and the first phase was opened on 19th October 2002.

Figure 1 shows the metro's alignment. The 11-km route consists of two metro lines connecting the island of Amager in the south with the city terminus at Nørreport on the island of Sjælland. Metro line 1 (M1) runs to a new town Ørestad in west Amager while metro line 2 (M2) runs to Lergravsparken in east Amager. The two lines meet on the Amager side of the Harbour corridor, just before Knippelsbro Bridge where the line goes underground.

The new town Ørestad will expand over the next 20 years to an area of 310 hectare, providing 60,000 jobs, 20,000 education places and 20,000 dwellings. Some larger companies have built new offices in Ørestad: Telia, Copenhagen Energy, Keops and Ferring. The Danish Broadcasting Corporation will transfer all its activities to a new television centre in Ørestad in 2006. The University of Copenhagen has been enlarged in the area, and the construction of an IT University is being considered.

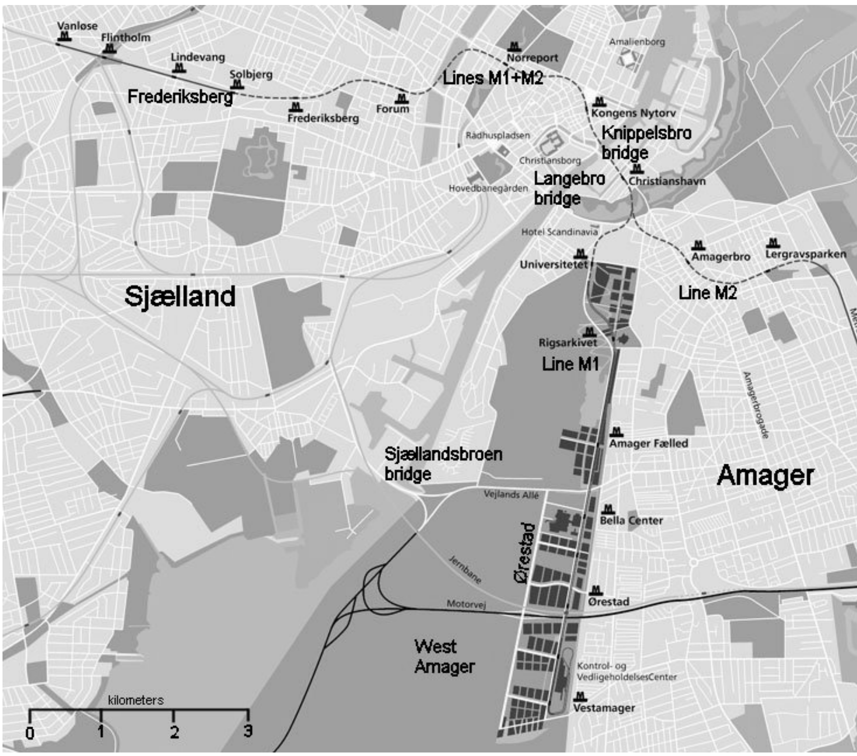

Figure 1: Alignment of the M1 and M2 metro lines.

Phase 2 of the metro opened in 2003, linking another part of the city, Frederiksberg, with the city centre. This phase was split into two smaller phases; phase 2A, between Nørreport and Frederiksberg opened in May 2003, and phase 2B, between Frederiksberg and Vanløse opened in October 2003. M1 and M2 metro lines continued their alignment prom phase 1 to phases 2A and 2B. With phase 2 completed, the metro system had a total length of 16 km and consisted of 17 stations, of which eight were underground.

Phase 3, the last projected phase of the Copenhagen Metro, will continue line M2 from Lergravsparken station to Copenhagen's international airport at Kastrup. This phase will open for operation in 2007. The full metro system will be a 22-km network, of which 11 km will be underground.

According to the original 1996 plans, phases 1 and 2A supposed to open at the same time because of what only the joint construction costs were given. The first budget of the two phases was DKK 6.7 billion (approximately EUR 900 million), while the final costs were DKK 9.2 billion. The planned construction costs of phase 2B were DKK 0.5 billion while the final costs were DKK 1.3 billion. Finally, the planned construction costs of phase 3 were DKK 0,7 billion while the present contraction costs were DKK 1.7 billion. In total, the construction costs of the Copenhagen metro were about 50% higher than originally anticipated.

The 2003 Traffic Plan contains a proposal for the metro's phase 4, the City Ring, with construction costs amounting to DKK 15 billion (Greater Copenhagen Authority, 2004). Connecting areas close to the city centre the City Ring will provide good opportunities for interchanging at major metro and S-train stations. Various alignments were proposed. Phase 4 will not be built until 2015 at the earliest.

The Copenhagen Metro is fully automated and operated from a computer centre in Ørestad. The metro operates with a 2-minute headway during peak periods (i.e., 7-10 a.m. and 3-6 p.m.), while in the out of peak periods there is a 3-minute period between arrivals. The operational system allows a minimum headway of only 85 seconds between trains. The metro operates in a self-contained network.

As the metro network has been expanded, changes have been made to the bus service in the capital, including the introduction of a so-called A-line bus network. A-line buses are high-frequency city buses that operate without timetables. They cross the metro network frequently and therefore serve as an access/egress mode to/from the metro. Changes were made in bus supply to lessen competition with the metro and reinforce public transport in the capital by capturing a greater market share from car users and positive induced traffic.

1.2 Scope of the paper

Transport effects of the metro's phases 1 and 2A are presented in this article. The Langebro and Knippelsbro bridges define the so-called Harbour corridor. Data completed in this corridor refers to the metro's phase 1.

Data in the area of Frederiksberg was collected in the North-South corridor (which crosses the metro's phase 2A alignment between Forum and Frederiksberg metro stations) and in a catchment area defined by a circle with a 500m radius around the Frederiksberg metro station.

Traffic counts were completed in the period of 1996-2003 and refer to personal cars, bus passenger traffic and metro passenger traffic. Traffic counts were collected both in the Frederiksberg corridor and in the Harbour corridor. In the Harbour corridor a panel of 1.000 travellers was sampled via a postcard survey some six months before the opening of phase 1. In the catchment area in Frederiksberg, 500 respondents were included in a panel according to population statistics, i.e. age, gender and employment. Both panel data were completed twice, the first time six months before the metro's opening and the second time some six months after the metro's opening.

2 Analysis of traffic counts

2.1 The Harbour corridor

The available counts show a permanent increase in the car traffic over the Harbour corridor since 1996 while the bus traffic has had the opposite trend. Table 1 shows changes in counted car person trips and public transport traffic from 2002 to 2003 for an average workday caused by the metro's introduction in October 2002. According to the figures in the table 3,000 car person trips have shifted to the metro, a decrease of 2.9% relative to 2002. Accordingly, the car modal share across the corridor dropped by 4% from 2002 to 2003.

In a more optimistic scenario we assume that car traffic across the harbour corridor would continue to increase, following the available car statistics. Under this assumption, if the metro had not been built, we would end up with 107,100 car person trips across the two bridges in 2003. In this case, the metro infrastructure caused a drop in 2003 equal to 5,000 car person trips. In conclusion, between 3,000 and 5,000 car person trips in the corridor shifted to the metro from 2002 to 2003, a decrease of 2.9% to 4.7%.

Table 1: Observed car and public transport traffic across the Knippelsbro and Langebro bridges in 2002 and 2003; person trips on an average workday and shares.

Mode	Traffic counted in 2002	Traffic counted in 2003
Car traffic	105,100 (60%)	102,100 (56%)
Bus traffic	69,000 (40%)	42,800 (24%)
Metro traffic	-	36,500 (20%)
Total	174,100 (100%)	181,400 (100%)

After the metro opened, 79,300 public transport day trips were counted across the corridor, an increase of 10,300 trips over 2002. The share of public transport trips across the corridor rose by 4% from 2002 to 2003. Bus traffic across the corridor decreased by 26,200 passenger trips from 2002 to 2003. Assuming a constant level of bus traffic in 2003 relative to 2002 if the metro had not been built, the share of bus trips shifting to the metro would be 38.0%. However, by extrapolating the bus traffic trend for the period 1996-2002, we calculated that, without the metro, bus traffic across the corridor in 2003 would be 68,200 trips. In that case, 25,400 bus trips would have shifted to the metro, a decrease of 36.8%. In conclusion, between 25,400 and 26,200 bus trips in the corridor shifted to the metro from 2002 to 2003, a decrease of 36.8% to 38.0%.

In absolute figures, there were 7,300 more person day trips over the harbour screen line in 2003 than in 2002, a general traffic increase of 4.2%. 1,000 of those trips occurred as a result of socio-demographic and zone changes according to the Copenhagen traffic model runs (Jovicic and Hansen [7]). This means that 6,300 trips across the corridor were related to positive induced traffic, an increase of 3.6%.

Public transport traffic across the corridor increased by 10,300 trips from 2002 to 2003, a general traffic increase of 14.9%. A minimum of 3,000 and a maximum of 5,000 of these trips were shifted from car traffic. The Copenhagen traffic model also predicted that without the changes in public transport infrastructure, public transport traffic would increase by 700 day trips between 2002 and 2003. This means that the metro-related increase in public transport traffic across the corridor (i.e., public transport induced traffic) was in the range of between 4,600 and 6,600 day trips. This gives a public transport induced traffic increase across the corridor of 6.7% to 9.6% in 2003 relative to 2002. Furthermore, assuming that 4,600 to 6,600 new public transport trips across the corridor relate to the metro, positive induced traffic accounts for 12.6% to 18.1% of metro traffic across the corridor. Table 2 summarises the conclusions based on traffic counts.

Table 2: Traffic growth, induced traffic and modal changes across the Harbour corridor from 2002 to 2003 based on traffic counts.

	Trips	Percentage values
General traffic growth	7,300	+4.2%
Public transport traffic growth	10,300	+14.9%
General induced traffic	6,300	+3.6%
Public transport induced traffic	4,600 to 6,600	+6.7% to +9.6%
Metro induced traffic	4,600 to 6,600	+12.6% to +18.1%
Car traffic decrease	3,000 to 5,000	-2.9% to -4.7%
Bus traffic decrease	25,400 to 26,200	-36.8% to -38.0%

2.2 The Frederiksberg corridor

Table 3 shows changes in counted car person trips and public transport traffic from 2002 to 2003 for an average working day caused by the metro's introduction in May 2003 in the Frederiksberg corridor. According to the figures in the table 4,500 car person trips have shifted to the metro, a decrease of 6.5% relative to 2002. Accordingly, the car modal share across the corridor dropped by 6% from 2002 to 2003.

If we follow the historical trend of car traffic development in the area then if the metro had not been built, we would end up with 70,500 car person trips across the Frederiksberg corridor in 2003. In this case, the metro infrastructure caused a drop in 2003 equal to 5,200 car person trips, a decrease of 7.5%.

After the metro opened in Frederiksberg, 29,600 public transport day trips were counted across the corridor, an increase of 6,600 trips over 2002. The share of public transport trips across the corridor rose by 6% from 2002 to 2003. Bus traffic across the corridor decreased by 4,900 passenger trips from 2002 to 2003. Assuming a constant level of bus traffic in 2003 relative to 2002 if the metro had not been built, the share of bus trips shifting to the metro would be 21.2%. However, by extrapolating the negative bus traffic trend for the period 1996-2002, we calculated that, without the metro, the bus traffic across the corridor in

2003 would be 22,400 trips. In that case, 4,300 bus trips would have shifted to the metro, a decrease of 18.7%.

Table 3: Observed car and public transport traffic across the Frederiksberg corridor in 2002 and 2003; person trips on an average workday and shares.

Mode	Traffic counted in 2002	Traffic counted in 2003
Car traffic	69,800 (75%)	65,300 (69%)
Bus traffic	23,000 (25%)	18,100 (19%)
Metro traffic	-	11,500 (12%)
Total	92,800 (100%)	94,900 (100%)

In absolute figures, there were 2,200 more person day trips over the harbour screen line in 2003 than in 2002 giving a general traffic increase of 2.3%. The Copenhagen traffic model predicted that only 100 trips occurred as a result of socio-demographic and zone changes. This means that 2,100 trips across the corridor were related to positive induced traffic, an increase of 2.2%.

Public transport traffic across the corridor increased by 6,600 trips from 2002 to 2003, a general traffic increase of 28.7%. A minimum of 4,400 and a maximum of 5,100 of these trips were shifts from car traffic. The Copenhagen traffic model also predicted that without the changes in public transport infrastructure, public transport traffic would increase by 700 day trips between 2002 and 2003. This means that the metro-related increase in public transport traffic across the corridor (i.e., public transport induced traffic) was in the range of between 1,500 and 2,200 day trips. This gives a public transport induced traffic increase across the corridor of 6.5% to 9.6% in 2003 relative to 2002. Furthermore, assuming that 1,500 to 2,200 new public transport trips across the corridor relate to the metro, positive induced traffic accounts for 13.0% to 19.1% of metro traffic across the corridor. Table 4 summarises the conclusions based on traffic counts in the Frederiksberg corridor.

Table 4: Traffic growth, induced traffic and modal changes in the Frederiksberg corridor from 2002 to 2003 based on traffic counts.

	Trips	Percentage values
General traffic growth	2,200	+2.3%
Public transport traffic growth	6,600	+28.7%
General induced traffic	2,100	+2.2%
Public transport induced traffic	1,500 to 2,200	+6.5% to +9.6%
Metro induced traffic	1,500 to 2,200	+13.0% to +19.1%
Car traffic decrease	4,500 to 5,200	-6.5% to -7.5%
Bus traffic decrease	4,300 to 4,900	-18.7% to -21.2%

3 Analysis of panel data

Traffic growth and induced traffic, as measured in Tables 1 to 4, can be caused by changes in personal trip rates and changes in the choice of destination. The measured changes in the trip rates in the panels are presented in the following two sections.

3.1 The Harbour corridor

The average trip rate in the sample of 1.000 persons, drawn from the travellers across the Harbour corridor, was 3.53 trips per day in both the before and after surveys, thus the average trip rate did not change from 2002 to 2003. In Table 5 trip rates are shown for the two samples split by travel modes. To sum up the average day trip rate the table also refers to trips conducted by slow modes (i.e., walking and cycling).

The car trip rate was almost identical for the two panels, in the before panel the trip rate was 1.35 while in the after panel the trip rate was 1.38. The trip rate for public transport modes increased though from 0.50 trips per day in the before panel to 0.70 in the after panel. This happened at the expense of the slow modes, whose trip rate decreased by 0.23 trips per day from 2002 to 2003 (a 14% decrease).

Table 5: Trip rates (number of trips per person per day) for different travel modes in the Harbour-corridor panel survey.

	Before panel	After panel
Modes	Trip rate	Trip rate
Slow modes	1.68	1.45
Car	1.35	1.38
Bus	0.29	0.24
Train	0.21	0.34
Metro	-	0.12
Total	3.53	3.53

Within the public transport modes the bus trip rate decreased slightly between the two surveys, possibly due to shift to the metro. Furthermore, the metro trip rate was lower than either the bus or the train trip rate, most likely because the metro network is rather simple compared to the train network and, in particular, the bus network. As the main travel mode, the metro offers a limited number of travel destinations compared to bus and train. Accordingly, the metro is used as access/egress mode for longer trips, where train is the main travel mode. This also explains why the train trip rate increased in the after panel relative to the before panel by 60%.

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3.2 The Frederiksberg catchment area

As shown in Table 6, among the 500 respondents in the Frederiksberg catchment area the trip rate rose from 3.17 to 3.65 trips per day per person from 2002 to 2003.

The car trip rate increased from 0.88 to 1.02 trips per day per person in the panel, an increase of 15%. For the slow modes, the trip rate increase equals 10%. The trip rate for public transport modes increased from 0.38 to 0.52, i.e. about 40%.

Among the public transport modes the bus trip rate decreased by 25% between the two panels while the train trip rate rose by 20% from 2002 to 2003. We conclude therefore that the metro serves as access/egress mode for the longer trips (with train as the main travel mode), while for the shorter public transport trips the metro is the main travel mode.

Table 6: Trip rates for different travel modes in the Frederiksberg panel survey.

	Before panel	After panel
Modes	Trip rate	Trip rate
Slow modes	1.91	2.11
Car	0.88	1.02
Bus	0.24	0.18
Train	0.14	0.17
Metro	-	0.17
Total	3.17	3.65

4 Discussion and further research

The existing literature on the subject of transport impacts of new public transport systems shows similar trends but of varying magnitudes. These infrastructures result in positive public transport induced traffic, and the majority of new mode passengers shift from pre-existing public transport modes, while former car users usually make up a smaller market share. About 70% of the Croydon Tramlink passengers are former bus users (Copley et al. [1]). The percentage shift from car traffic ranges from 16% in Athens (Golias [2]) to 26% in Madrid (Monzon [9]).

In general, public transport induced traffic is dependent on modal shifts from non-public transport modes (e.g., car), changes in destination choice and changes in trip rate. Traffic counts in the two corridors in this study, the Harbour corridor and the Frederiksberg corridor, show identical public transport induced traffic, ranging from 6.5% to 9.6%. Public transport induced traffic was 12% after the introduction of the Supertram system in Sheffield (W.S. Atkins Consultancy [10]) and 13% one year after a reorganisation of the bus system in Jönköping (Johansson and Svensson [5, 6] and Holmberg et al. [4]). The metro induced traffic was also identical in the two corridors, ranging from 12.5% to 19%.

In the Harbour corridor the travellers' trip rate did not change in the two panels. Also the car traffic decrease in the after metro situation was of a reasonable small magnitude (3% to 5%). Therefore, the induced traffic in the Harbour corridor was mainly defined by changes in the destination choice.

In the Frederiksberg corridor, a strong increase in the trip rate was witnessed, ranging from 3.17 trips per day in the before survey to 3.65 trips per day in the after survey. As expected, the public transport trip rate rose most significantly compared to trip rates by other modes. Also, the car shift to the public transport modes was larger in this corridor than in the Harbour corridor, i.e. the traffic counts showed a decrease in car traffic between 6.5% and 7.5%. This happened because the Frederiksberg residents have experienced an increase in the travel utility by shifting from car to the combination of metro and train modes, with the interchange at the Nørreport station. This is partly due to the existing travel patterns, which are suitable to the new infrastructure (many dwellings/working places are covered by the Metro network in Frederiksberg), and partly due to a high car congestion level in the Frederiksberg corridor.

The metro's post-opening period referred to in this article is six months long. Unfortunately, this period was characterised by many operational troubles causing the 'metro adopting period' to be longer than six months. To build a more realistic picture of the metro's transport impacts in Copenhagen, it is important to continue conducting travel surveys at least for one more year.

The modal shift from bicycle was not included in the analysis of traffic counts because of a small number of available counts. On the other hand, those available bicycle counts are influenced largely by weather conditions, which cannot be corrected for. Also, in the Frederiksberg corridor, we counted traffic at only the four largest traffic sections while omitting a number of smaller traffic sections along the corridor. This has reduced the quality of the obtained counts because bikers are bound to a specific route to a much smaller scale than the public transport users and car travellers. To measure a potential shift from bicycle to metro it is thus necessary to analyse the existing panel data in a more detailed level by observing the travel patterns and route preferences.

References

[1] Copley, G., Thomas, M. and Georgeson, N. (2002). Croydon Tramlink impact study. European Transport Research Conference. September 9-11. Cambridge, UK.

[2] Golias, J. C. (2002). Analysis of traffic corridor impacts from the introduction of the new Athens Metro system. Journal of Transport Geography. Volume 10, Issue 2, June 2002. Pages 91-97.

[3] Greater Copenhagen Authority (2004). Traffic Plan 2003. Report no. 87-7971-110-3. Denmark.

[4] Holmberg, B., Johansson, S. and Svensson, H. (1999). Evaluation of the Reorganization of Public Transport in Jönköping. Institutionen för trafikteknik, Tekniska Högskolan i Lund, Lund University, Sweden.

[5] Johansson, S. and Svensson, H. (1999a). Har kollektivtrafikomläggningen påverkat resvanorna i Jönköping. Institutionen för trafikteknik, Tekniska Högskolan i Lund, Lund University, Sweden.
[6] Johansson, S. and Svensson, H. (1999b). Vad tycker resenärerna i Jönköping om trafikomläggningen? Institutionen för trafikteknik, Tekniska Högskolan i Lund, Lund University, Sweden.
[7] Jovicic, G. and Hansen, C. O. (2003). A Passenger Travel Demand Model for Copenhagen. Transportation Research, Part A. Volume 37. Pages 333-349.
[8] Knowles, R. (1996). Transport impacts of Greater Manchester's Metrolink light rail system. Journal of Transport Geography. Volume 4, Issue 1, March 1996. Pages 1-14.
[9] Monzon, A. (2000). Travel demand impacts of a new privately operated suburban rail in the Madrid N-III corridor. European Transport Research Conference. September 7-11. Cambridge, UK.
[10] W. S. Atkins Consultancy (2000). Supertram (Sheffield) monitoring study. Final report.